STUDIES IN GUJARATI PHONOLOGY AND PHONETICS

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TRANSCRIPTIONS

[n̈]	:	[ŋ]
0	:	ɔ
E	:	ɛ
a	:	a
[..]	:	phonetic transcription of murmured vowel, e.g. [a̤]
/ah/	:	phonemic transcription of murmured vowel, e.g. [bar] /bahr/ 'out'
$[d^h], [t^h]$	:	phonetic transcription of the aspirated stops which are normally written as dh, th, in this thesis.
ʋ	:	Labio-dental consonant. Frictionless. (See The Principles of the IPA:10.)

ABBREVIATIONS

JASA	:	Journal of the Acoustical Society of America
Asp.	:	Aspirated
Unasp.	:	Unaspirated
Imp.	:	Imperative
adj.	:	Adjective
pro.	:	Pronoun
Excl., Incl.	:	Exclusive, Inclusive
Sg., pl.	:	Singular, plural
Masc., Fem., Neut.	:	Masculine, Feminine, Neuter
n.	:	Noun
I, II, III	:	I. Person, etc.
F_o	:	The voice fundamental, or the fundamental harmonic
F_1, F_2, etc.	:	Formant one, Formant two, etc.
F_s	:	Sub-formant
F_x	:	Extra formant or resonance
[i], [e], etc.	:	All samples of [i], [e], etc.
In RT, In SK, etc.	:	In the speech or in the particular pronunciation of RT, SK, etc.
F-frequency	:	Formant frequency
IPA	:	International Phonetic Association
ARIPUC	:	Annual Report of the Institute of Phonetics, University of Copenhagen
TCLP	:	Travaux du cercle Linguistique de Prague

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CHAPTER I

INTRODUCTION

I.1. Gujarat and Gujarati

Gujarati is an Indic language spoken mainly by the people living in the state of Maha-Gujarat -- or Gujarat as it is usually called. There is, however, also quite a number of Gujarati speaking people in the state of Maharashtra (see the map). Most of the Gujaratis, who lived formerly in Kenya and Uganda, have moved to Canada and Great Britain. That may be also true of those who lived in South Africa.

Gujarati language belongs to the Indo-Aryan sub-branch of Indo-Irarian, which again is a branch of the Indo-European family of languages.

According to the census of India (1971)[1], the number of persons speaking Gujarati is approximately 25.6 million. The same handbook lists three distinct dialects of Gujarat: (i) the Northern dialect spoken between the Banas and Sabarmati rivers, (ii) the central dialect spoken between the Sabarmati and Narmade rivers, and (iii) the Southern dialect spoken beyond the Narmade river and south of the Tapti river. It is further stated that besides the regional dialects there exist various occupational and social (caste) dialects.[2] It is evident that the

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[1] Appendix II, page 333.

[2] pp. 269-70.

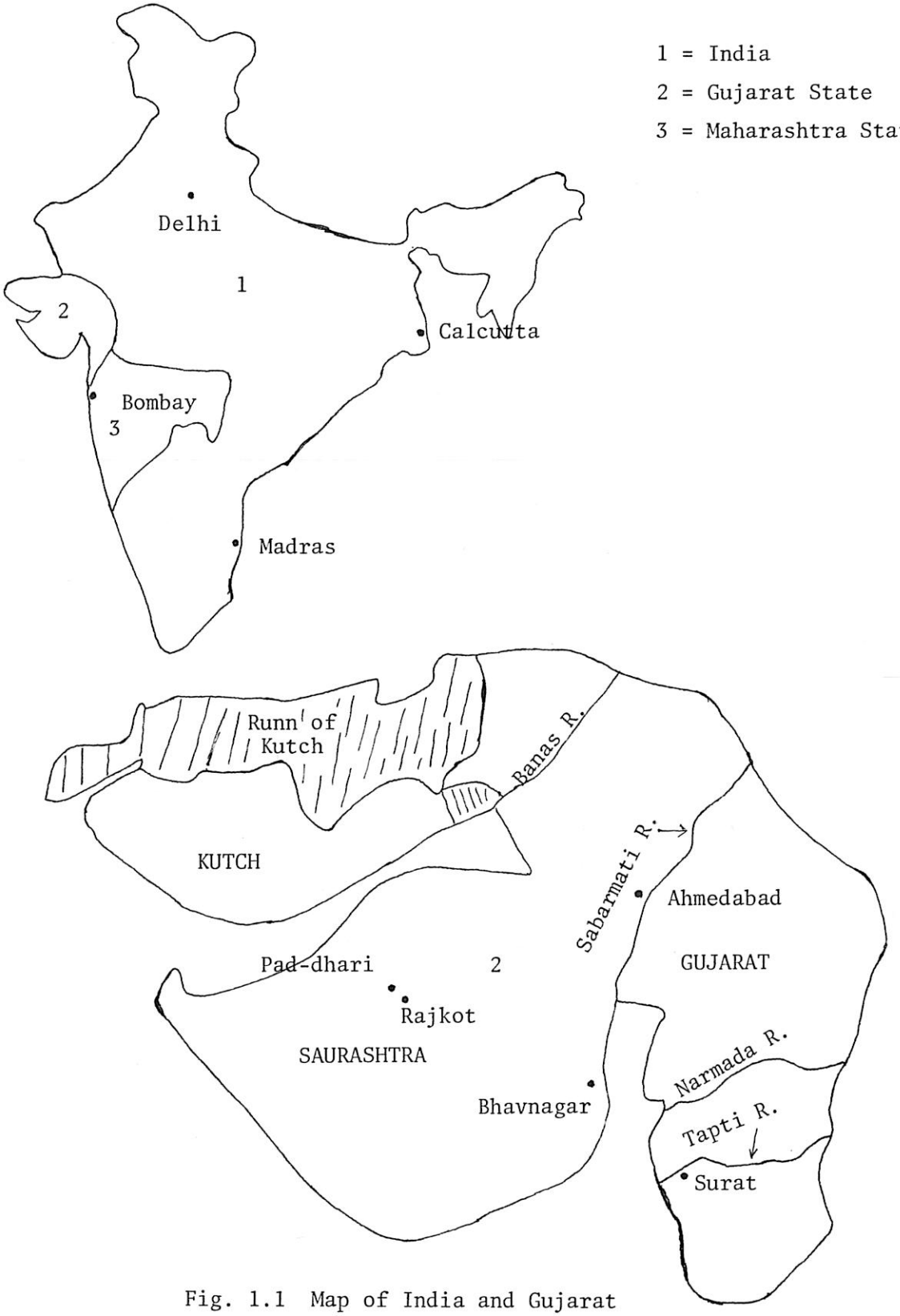


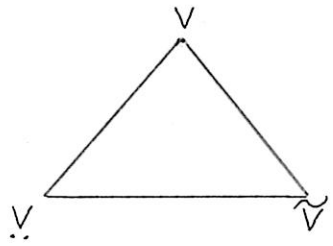
Fig. 1.1 Map of India and Gujarat

criterion of deciding the dialect regions is rather geographical than linguistic.

In the absence of a real linguistic survey of Gujarat,[3] we may perhaps just start from the most common geographical division of Gujarat into Kutch, Saurashtra, and Gujarat proper. Kutch is the North-Western part of the state. Saurashtra is the peninsula south of Kutch, and Gujarat proper is made up of the Eastern part of the country (see the map). Apart from the dialect spoken in Kutch (which has some relations to Sindhi language), all dialects of Gujarati are very similar and mutually understandable. Besides the dialects, a sort of standard Gujarati is spoken all over the state.

I.2. A linguist's interest in Gujarati.

A linguistic or phonetic researcher is generally interested in the structure of all languages. If a language has, however, some special or unique features, he gets naturally more interested in that. Gujarati has some phonological characteristics which are of great interest both to a linguist and to a phonetician. It has a unique vocalic system showing a three-way contrast between the oral, nasalized, and murmured or breathy vowels (see section II.2.6):



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[3] Grierson (1903-28) is quite old and outdated, and does not contain any well-defined description of the dialects.

Gujarati also has a series of retroflex consonants, which are in contrast to the corresponding dental and alveolar consonants (see Chapter II): t-ṭ, d-ḍ, l-ḷ, n-ṇ, r-ṛ.

The phonological interpretation of the murmured (breathy) vowels is a matter of interest to any linguist. Similarly, the phonetic analysis of the murmured vowels and the retroflex consonants is of great interest to phoneticians. This defines the scope of the present thesis.

I.3. The scope of the present thesis.

First of all, a brief sketch of Gujarati phonology is presented, except of its suprasegmental phonemes. First, the phonemes of Gujarati have been set up. The phonemic interpretation is not exhaustive. It serves as a starting point.

The phonemes of Gujarati have been described in the distinctive feature system of Roman Jakobson. Next follows a formant analysis of Gujarati clear, nasalized, and murmured vowels, and their comparison based on that. Finally, a palatographic and spectrographic study of the retroflex and corresponding non-retroflex (or dental/alveolar) consonants of Gujarati is presented.

CHAPTER II

PHONOLOGY OF GUJARATI

II.1. Some previous works.

The traditional grammars of Gujarati do not give any description of the phonological system. They simply mention the alphabet and give some rules of pronunciation. Some scholars of Gujarati language and literature have tried to describe the structure of Gujarati. Divatia (1921) discusses the historical development of Gujarati. He gives diachronic explanations for the synchronic usage. Turner (1921) is perhaps the first scholar who gives a systematic description of the history of Gujarati language. T.N. Dave (1935) describes the structure of the sixteenth century Gujarati, based on a particular text. P.B. Pandit[1], perhaps for the first time, treats various aspects of Gujarati phonology according to the principles of modern descriptive linguistics. Cardona's (1965) seems to be the first descriptive reference grammar of Gujarati, written for linguists and language teachers.

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[1] See the bibliography for a list of some of his works. See also Pandit (1957) for his transcription of the murmured vowels and aspirated stops.

II.2.1. Phonemes.

It is common to distinguish the following vowels and consonants in Gujarati.

II.2.11. Vowels.

ORAL

Clear		Murmured (breathy)		
i	u	i̤		ṳ
e	o	e̤		o̤
E	0	E̤	ə̤	0̤
a		a̤		

NASAL (Nasalized)

ĩ		ũ
ẽ	ə̃	õ
	ã	

II.2.12. Consonants.

		Labial	Dental	Retroflex	Palatal	Velar	
stops	Unasp. vl.	p	t	ṭ	c	k	
	Unasp. vd.	b	d	ḍ	j	g	
	Asp. vl.	ph	th	ṭh	ch	kh	
	Asp. vd.	bh	dh	ḍh	jh	gh	
fricative & Sibilants			s	ṣ	ś		h
Nasals		m	n	ṇ	ñ	ṅ	
Liquids			r	ṛ			
			l	ḷ			
Semi-vowels		ʋ			y		

With a few exceptions (see Chapter III), these vowels and consonants can be shown to form distinctive opposition in the same environments and said to be phonemic. It is possible, however, to make further reductions by interpreting murmured vowels, nasalized vowels and aspirated stops as clusters. These reductions will be discussed after the less controversial distinctions (place of articulation in vowels, and place and manner of articulation in consonnts) because they presuppose a particular

analysis of both vowels and consonants.

II.2.21 The vowels.

The vowels of Gujarati are distinguished by their place of articulation and the degree of aperture. There are eight clear vowel phonemes in Gujarati: /i/ high front, /e/ mid front, /E/ low front, /ə/ mid central, /a/ low central, /u/ high back, /o/ mid back, and /O/ low back.

	FRONT	CENTRAL	BACK
HIGH	i		u
MID	e	ə	o
LOW	E	a	O

II.2.22 The front vowels.

The contrast between /i/, /e/, and /E/ will be clear from the following examples:

/is/	'upper end of bedstead'	/ʋir/	'brave'
/ek/	'one'	/ʋer/	'revenge'
/Eś/	'enjoyment'	/ʋEr/	'dust of the wood'

Of these, /i/ has greater freedom of occurance in the sense that it occurs in all positions, for instance, /ila/ 'girl's name', /bi/ 'seed', /ʋir/ 'brave', /khə mis/ 'shirt', /kElə ʋṇi/ 'education'.

The opposition between /e/ and /E/ is restricted to the initial

position or initial syllable only, while it has not been regularly maintained in other positions. The pronunciation may vary according to individual speakers:

/mel/	'put'	/didhel~ didhEl/	'given'
/mEl/	'dirt'	/həwe ~ həwE/	'now'
/ʊer/	'revenge'		
/ʋer/	'dust of the wood'		

Pandit (1955:653) discusses the situation: 'Open E and O are found either initially or in the initial syllables only. There are no medial E and O in Gujarati. In final positions, however, these sounds are half open and there are no contrastive examples available.' I have, however, observed occurance of the medial E and O in free variation with e and o. The speakers do not always keep the two degrees of openness apart in the medial and final positions.

II.2.23. The back vowels.

The opposition between /u/, /o/, and /O/ is examplified below:

/mul/	'root'	/un/	'wool
/goḷ/	'round'	/om/	'a mantra'
/goḷ/	'molasses'	/Oṇ/	'this year'

The distribution of the phoneme /u/ is quite systematic. It occurs in all positions: /ukərṛo/ 'refuse (of the garbage)', /əkudrəti/ 'unnatural',

/beṭhaḷu/ 'lazy.

Like /e/ and /E/, the opposition between /o/ and /0/ is restricted to the initial position or syllable only. In other positions the pronunciation may vary according to the individual speaker (see II.2.22.):

/mor/ 'peacock'

/m0r/ 'mango blossom'

/koḷi/ 'a caste'

/k0ḷi/ 'blossomed'

/bhagoḷ ~ bhag0ḷ/ 'precincts of a village or town'

/maro ~ mar0/ 'mine'

It may also be added that I have only six vowel phonemes in my dialect, which is known as the Halari dialect of Sauashtra: /i e a ə o u/.

II.2.24. The central vowels.

/ə/ and /a/ are in opposition in initial and medial positions.

/ə j/ 'name of a person'

/aj/ 'today'

/tər/ 'swim (II Imp.sg.)

/tar/ 'rescue (II Imp.sg.)

/əjgər/ 'python'

/ajkal/ 'these days'

There is a restriction on the occurrence of /ə/. It does not occur in the final position, although orthographically it is always written. It is possible, however, to have a slight release of /ə/ occasionally after the word-final consonatns. Moreover, /ə/ occurs in all learned Sanskrit loans. [d^{h}ə nusyə] 'bow', [pascatyə] 'western', [usnə] 'warm', [varsneyə] 'a surname'.

II.2.25. The long vowels.

The long vowels [i:], [e:], [E:], [0:], and [u:] are generally listed as phonologically distinctive units in Gujarati grammars. The Gujarati alphabet also lists [i:] and [u:] as distinctive units. There is no need, however, to set up long vowels as phonemes as there is no opposition between the short and long vowels. Thus, it is possible to interpret the long vowels as the allophones of short vowel phonemes. The eight clear vowels -- perhaps with the exception of /ə/ -- are generally relatively longer in word-final syllables:

[əmiri:]	'wealthiness'
[tabele:]	'at the stable'
[pərpoto]	'bubble'
[aśa:]	'hope'
[məhara:j]	'king'
[rumjhu:m]	'tinkling (of the bells)'

For the discussion on /ə/ see section II.2.24.

Pandit (1958) posits a juncture phoneme /+/ to take care of the vowel length.

II.2.26. The murmured and nasalized vowels.

The murmured vowels have the same degree of openness as the clear vowels, that is, they are also eight in number. The nasalized vowels, however, do not distinguish between the open and close e and o. Thus, there are only six nasal vowels: ĩ, ẽ, ə̃ , ã, õ, ũ.

There is a contrast between the clear, murmured, and nasalized vowels.

It is very dubious whether there is any contrast between the clear, nasalized and the murmured nasalized vowels. In my own speech, and in the speech of my informants, such contrast does not exist.

See II.2.51 and II.2.6 for further discussion.

II.2.31. The Stops.

Like other Indic languages, Gujarati has an extensive number of stop consonants, as can be seen in II.2.12. They are partly distinguished by the position of articulation: labial, dental, retroflex, palatal, and velar. The retroflex consonants are often called cacuminals (cacumen = top of the palate) in the Indic and older European tradition. They are articulated with the tongue tip curled back, often as far back that it touches the front or even mid part of the hard palate. But they may also be somewhat less retracted. If that happens, they may be post-alveolars. Pandit (1958) calls them alveolars. More discussion on the retroflexes is found in II.3.

The palatals are prepalatals, but they may also have some contact in the post-alveolar region. However, the tip of the tongue is not curled back in contradistinction to what is done in case of the retroflexes. They are normally affricated. This is very often the case wtih palatal stops because it is difficult to make a clear cut closure at the top of the palate. There is no basis for interpreting them as clusters of two phonemes, viz. as t + ś and d + ź, since ź does not exist as a phoneme in Gujarati.

In the following pages examples of the various consonants in connection with the vowel a are given. They do not always constitute

minimal pairs, but it is clear from the examples that they are found in the same environment.

II.2.32. /p/ and /b/:

/pan/ 'betel leaf' /palɜk/ 'protector

/ban/ 'prohibition' /balɜk/ 'child'

/pal/ 'a surname' /kapo/ 'cut' (noun, masc.)

/sap/ 'snake'

/bap/ 'father'

/ph/ and /bh/:

/phal/ 'crop' /sapho/ 'turban'

/bhal/ 'forehead' /abho/ 'surprised'

/saph/ 'clear'

/abh/ 'sky'

II.2.33. /t/ and /d/:

/tara/ 'girl's name' /mata/ 'mother'

/dara/ 'wife' /mada/ 'female'

/tan/ 'musical note'

/nat/ 'caste'

/nad/ 'sound'

/sath/ 'company (of somebody)'

/sadh/ 'ambition, intention'

II.2.341 The retroflex stops.

/ṭ/ and /ḍ/:

/ṭal/ 'baldness' /paṭa/ 'railroad tracks'

/ḍal/ 'branch' /paḍa/ 'male buffalos'

/aṭ/ 'weaver's tool'

/aḍ/ 'obstruction'

/ṭh/ and /ḍh/:

/ṭham/ 'place' /paṭhan/ 'Pathan'

/ḍhal/ 'shield' /caḍhan/ 'ascent'

/saṭh/ 'sixty

/gaḍh/ 'intimate'

II.2.342 [ḍ] and [ṛ].

The phoneme /ḍ/ has two allophones: [ḍ] and [ṛ]. [ḍ] is retroflex voiced stop. It occurs in the following positions.

(1) In word-initial position: [d̤abo] 'left';

(2) After a retroflex [ɳ] : [pəɳd̤it] 'learned';

(3) In intervacalic position, if the segment after the second vowel is [l̤], [n̤], or [r̤] :

[pə d̤ə l̤] 'eyelashes'

[udə n̤] 'flying'

[ud̤ar̤] 'fly' (II. Imp. sg. causative).

[r̤] occurs in other positions.

Pandit (1958:217) gives further conditions of the occurence of [d̤]. According to him, [d̤] also occurs in the following positions:

(i) Intervocally, if the segment after the second vowel is [r]: [gə d̤ə r] 'goat';

(ii) before [l]; [pud̤lo] 'pancake;

(iii) after a nasalized vowel: [pẽd̤o] 'sweet'.

Cordona (1965) gives the same distribution.

I have noticed alternative pronunciations with [r̤] in all of the above mentioned examples. Hence, there is a sort of coalescence between [d̤] and [r̤] in the situations noted above, and also in the word-final position and intervocalic position: [ad̤]~ [ar̤] 'obstruction'. Note that this happens in words with [d̤]; there are other words which have only [r̤]: [sar̤i] 'sari', [sir̤i] 'staircase'; there is only partial overlapping. /d̤/ may be pronounced [r̤], but /r̤/ is not pronounced [d̤].

The discrepancy between Pandit and me may be explained by the fact that there are minor dialectal variations in Gujarati, and one may not have observed some pronunciations noticed by others. Hence, further

investigations are necessary.

II.2.35. The palatals.

/c/ and /j/:

/cal/ 'strain'(II Imp. sg.) /ɔckən/ 'long coat'

/jal/ 'net' /ɔjgər/ 'python'

/kac/ 'glass'

/kaj/ 'work'

/ch/ and /jh/:

/chal/ 'bark /pachi/ 'again'

/jhal/ 'hold' (II Imp.sg.) /dajhi/ 'burnt' (III sg. fem.)

/kach/ 'small dhoti'

/bajh/ 'fight' (II Imp.sg.)

II.2.36. The velars.

/k/ and /g/:

/kal/ 'yesterday' /sakər/ 'sugar'

/gal/ 'cheek' /sagər/ 'sea'

/śak/ 'vegetables'

/ag/ 'fine'

/kh/ and /gh/:

/khal/ 'skin'

/ghal/ 'put (it) in' (II Per. Imp.sg.)

/makhi/ 'fly'

/aghi/ 'away'

/rakh/ 'ash'

/ɒagh/ 'tiger'

II.2.37. /r/ and /l/:

/rab/ 'porridge'

/labh/ 'benefit'

/urmi/ 'emotion'

/julmi/ 'cruel'

/car/ 'four'

/cal/ 'walking style'

II.2.38. The retroflex /l̤/ :

The alternations of /l̤/ have been observed: with one tap and without tap. Both are in free variation. /l̤/ does not occur in word-initial position. In orther positions it is in the contrast with /l/:

/palo/ 'grass'

/palo̤/ 'banks (of rivers)'

/kal/ 'yesterday'

/kal̤/ 'time; death'

/alya/ 'gave' (masc., pl.)

/balya̤/ 'burnt' (masc., pl.)

II.2.39. Sibilants.

There is contrast between the dental and palatal sibilants, but retroflexion in sibilants is a conditioned feature. not distinctive. The

retroflex ṣ is still listed in Gujarati alphabet and is treated to be a phonologically distinctive unit, but it is not pronounced as a retroflex sibilant except before a retroflex consonant. Thus, in words like ṣəṭkOn "hexagon', ṣəṭ 'six', paṣan 'stone', kṣəma 'pardon', dhənuṣyə, etc. the palatal [ś] is pronounced, whereas [əṣṭ] is pronounced with a retroflex sibilant.

/s/ and /ś/:

/sal/ 'hindrance'

/śal/ 'shawl'

/pas/ 'near'

/paś/ 'bondage'

/orəsyo/ 'small round piece of stone'

/kələśyo/ 'big glass

The phoneme /ś/ must be considered to have two allophones: a palatal sibilant [ś], and a retroflex sibilant [ṣ]. [ṣ] occurs medially before a retroflex consonant, [ś] occurs in other positions.

[ṣ]	[ś]
[əṣṭ] 'eight'	[śəṭkOn] 'hectagon'
[uṣṭrə] 'camel'	[paśan] 'stone'
[varṣneyə] 'surname'	
[uṣnə] 'warm'	
[səṣṭi] 'sixtieth (year)'	

II.2.4 The semi-vowels.

Of the two semi-vowels, /y/ is palatal, and /ʋ/ is labial:

/yar/ 'friend' /daya/ 'mercy'

/ʋar/ 'day (of the week)' /dəʋa/ 'medicine'

/gay/ 'cow'

/gaw/ 'sing' (II Imp.pt.)

There are two allophones of / /: a labio-dental frictionless [ ], and a labial [w]. [ ] occurs initially; [w] occurs in word-final position. Both var- freely in medial position.

[ʋ]		[w]	
[ʋar]	'day (of the week)'	[gaw]	'sing' (II Imp.sg.)
[ʋir]	'brave'	[saw]	'almost'
[ʋer]	'revenge'	[məharaw]	'king'
[dəʋa]	[dəwa]	'medicine'	
[nəʋnit]	[nəwnit]	'boy's name'	
[hələ̣ʋe]	[hələ̣we	'slowly'	

II.2.51. Nasal consonants and nasalized vowels.

As mentioned in section II.2.12, Gujarati has the following nasal consonants: [m, n, n̤, ñ, ṅ]. Of these, only [m] and [n] occur in word-initial position. They are in distinctive opposition:

/man/ 'honor' /mən/ 'mind'

/nam/ 'name' /nət/ 'bowed'

There is a three-way opposition between [m], [n], and [ṇ] medially between vowels, and before consonants. Also there is a three-way opposition in word-final in word-final position: /pamər/ 'wretched' /cimki/ 'warning' /pam/ 'obtain' (II Imp.sg.) /vanər/ 'monkey' /janki/ 'girl's name' /pan/ 'betel leaf' /manəs/ 'man' /maṇki/ 'swift mare' /paṇ/ 'stone'.

There are some restrictions on their occurrence in medial position as to the following consonant, but it is not so that [m, n, ṇ] are only found before their homorganic consonants (cf. Pandit 1957, p. 168, who rightly stresses this fact in contradistinction to what has been said by Firth and Allen). It has been shown in the above examples that all three occur before k.

It is thus evident that we have to set up at least three nasal consonant phonemes, /m/, /n/, and /ṇ/. The palatal nasal [n] and the velar nasal [ṅ], however, occur only as homorganic nasals before stops having the same point of articulation: [səṅco] 'machine'. [kəṅku] 'girl's name'.

As [m, n, ṇ] also occur before k, it is not possible to consider [ṅ] to be a variant of any of them. Thus, we have to set up a fourth nasal phoneme with a very restricted distribution. Pandit (1957) used the designation /N/ for this phoneme, which is velar before velars, and palatal before palatals.

It is not possible to analyse the nasalized vowels as vowel plus any of the three nasal phonemes /m/, /n/. or /ṇ/, since they are distinctly different from them:

[kã] 'why'

[kam] 'work'

[kan] 'ear'

[kan̤] 'consolation (for the dead)'.

But nasalized vowels can be considered to be clusters consisting of an oral vowel plus the nasal phoneme /N/, mentioned above, since there is no opposition between nasal vowel and vowel + ñ or n̤. This analysis has been proposed by Pandit (1957). According to Pandit, there is a positive reason for such an interpretation, since he has found free variation between an oral vowel + N and a nasalized vowel, e.g. [bəṅko] 'brave' may also be pronounced as [bə̃ko]. However, this alternation has not been observed by me.

Pandit sets up a fourth allophone of the phoneme /N/, which is [ə̃]. According to him, ə + ñ and ə + ṅ are not nasalized. He also finds that [ə̃] is nasalized only in the end before /s, ś, r, l, y, ʋ/ and any murmured vowel:

[kəə̃s] 'a king's name'

[səə̃yəm] 'control'

[səə̃ʋad] 'dialogue'

Such pronunciations have, however, been noticed by me only as free variations of a fully nasalized vowel: [kə̃s], [sə̃yəm], [sə̃vad]. Pandit also has observed such pronunciations in learned loanwords of Sanskrit.

II.2.52. The nasal phonemes.

Thus we set up four nasal phonemes in Gujarati: /m/, /n/, /n̤/, and

/N/. The retroflex /ṇ/ has two variants in free alternation: a retroflex flap nasal with one tap, and a retroflex nasal. /N/ has three allophones:

[n] palatal nasal; it occurs before palatal consonants;

[ṅ] velar nasal; it occurs before velar consonants;

[˜] nasalization of vowels

Examples have already been given. A few more are given below with /m/, /n/. and /n/:

/śaN/	[śã]	'what' (pl.)
/səNgh/	[səṅg^{h}]	'group'
/səNco/	[səñco]	'machine'
/śan/	[śan]	'pride'
/śaṇ/	[śaṇ]	'knife-sharpener'
/am/	[am]	'thus'

II.2.6. Aspiration, h, and murmur.

II.2.61. Consonant h.

In Gujarati, the consonant h occurs initially, medially, and finally. Medially, it is voiced. /saheb/ 'sir', /hajəṛ/ 'present', /həri/ 'Vishnu' /ʋahyat/ 'useless', /hahakar/ 'tumult, uproar', /maharaʋ/ 'emperor', /phateh/ 'success', /cah/ 'tea', /brahmən/ 'brahmin', /səhyadri/ 'name of mountain', /həʋe/ 'now', /haṭ/ 'shop'.

II.2.62. Stop consonants.

Aspiration is phonetically closely related to the consonant h, and it is possible to interpret aspirated stops as a cluster of stop + h. This analysis does not make any difficulties since the unaspirated stops and h both occur as separate phonemes, and since there is no phonological distinction between stop + aspiration and stop + h.

II.2.63. Murmured vowels.

Murmured (breathy) vowels are also phonologically related to h, and an analysis of murmured vowels into vowel + h has to be considered. However, that seems to be more problematic.

The peculiar characteristic of Gujarati murmured vowels has been observed by various scholars. Grierson (1927) pointed to the weak h in Gujarati. Firth (1950:52) referred to the 'breathy phonation' in contrast to the 'tight phonation' in Surti Gujarati. Chatterjee (1931) interpreted it as a 'glottal stop, or accompanying glottal release' (cf. Pandit 1957 for further discussion). Most of the Gujarati scholars, following Divatia (1921:115, 297) consider breathy phonation to be a special king of h, and not a vocalic feature. K.H. Dhruva (cf. Divatia 1921:297) described it as a vocalic feature and called it 'Prandhvani' (a breathy sound). Rejecting this view, Divatia called it a variety of the consonant h and labelled it as 'laguprayatna hakara' or 'laghuccarana hakara' (the weak h). Divatia calls the consonant h 'guruprayatna ha-kara' or 'strong h'. He uses the terms aurasya h (produced from the chest) or the weak h, and kəṇṭhya (glottal) or the strong h for the two kinds of h. The literature Gujaratis

and dictionaries generally refer to is as the ha-śruti, or a sort of h-sound.

Varma et al. (1960:267) also describe two kinds of h in Gujarati: "In addition to the glottal h, the aurasya h is also used in Gujarati at times, e.g. brəhmən , ahwan . In these examples the h-sound is produced from the chest. This h is also slightly heard in some tadbhava words: in the words əme , təme, jyare, tyare, etc., this h-sound is heard. It is called the h-śruti (h-sound)". [Translated from Hindi.].

The word tatsama means a learned loanword from Sanskrit (or other languages); tadbhava literally means 'derived from that', i.e. derived from tatsama, and hence the standard colloquial Gujarati word.

Note that the definition of h is incorrect and not phonetic. The example brəhməṇ is not clear; perhaps the word brahmən 'brahmin' is meant. The statement and the examples have not been explained. Also the statement about the weak 'h' is not correct. In fact, these are examples with murmured vowels, and murmured vowels are widespread in Gujarat.

The first phonological and phonetic description based on modern phonetic and linguistic principles has been given by Pandit (1957). Pandit interprets murmured vowels as vowels + h. He sets up a phoneme /h/ with two allophones: murmur [_] and aspiration [ʻ] (our transciprtion for murmur is [.]. The phoneme /h/ is defined by Pandit as having some sort of extra breath.

He writes: 'When it is similtaneous with the vowel it is murmur (murmur being described as sotto voce, with voicing and slight lowering of pitch), when not simultaneous with the vowel it is the aspiration of the previous consonant. Murmur is transcribed after the vowel, aspiration is transcribed after the consonant.' [Pandit (1957:169-170)].

A few examples of the murmured vowels and stop consonsants are given below:

/bar/ [bar] 'twelve /bahr/ [b̤ar] 'out'

/bhar/ [bhar] 'weight'

/ko/ [ko] 'somebody' /koh/ [k̤o] 'say'

/kho/ [kho] 'a game'

/por/ [por] 'last year' /pohr/ [p̤or] 'a measure of time'

Pandit's analysis is strongly supported by the following reasons:

(1) First of all, it may be mentioned that historically murmured vowels have developed from vowels + h and sometimes h + vowels. For instance, [b̤ar] was formerly [bəhar]. In modern Gujarati such pronunciations are not found as a regular feature, although they are often heard in emphatic speech or as a reading practice. Hence, in such cases the h disappears and the word is pronounced either with clear or with murmured vowel: [bar] or [b̤ar] 'out'.

(2) h + vowel may be pronounced as murmured vowel: [hori] or [o̤ri] 'boat'.

(3) The consonant h occurs as the aspirated release of stops: [lab^{h}] 'benefit'. In such cases the h may disappear, according to Pandit, and the preceding vowel is pronounced murmured: [l̤ab].

(4) The relationship between h and the murmured vowel is also apparent from the fact that murmured vowels do not occur after aspirated

stops. Only clear and nasalized vowels occur after aspirated stops: [t̤^{h}ik] 'alright', [c$^{h\tilde{}}$ik] 'sneeze'.

(5) Although it has been stated by Pandit (1957) and R. Dave (1967) that the murmured vowels do not occur in word-final position, a few such occurrences have been observed by me later: [s̤a̤] ~ [shah] 'a surname', [c̤a̤] ~ [cah] 'tea'. Pandit himself quotes one example: [ṳ̃] 'I'. It is still dubious whether this is a feature of a couple of individual speakers or a common feature of Gujarati. More investigation is necessary.

(6) Words which do not belong to any of the above types are always pronounced with a clear vowel without any possibility of alternation: [bar] 'twelve', [sar] 'motto', [sonṹ] 'gold. Thus the pronunciation of the mucmured vowel is optional to some Gujarati speakers, but the pronunciation of the clear vowels stated in other types of words is stable.

Thus, intervocalic h is the most common source of murmured vowels. But, as mentioned above, there are also other cases where the variation between h and murmured vowel have been observed: [hori] or [o̤ri], [lab^{h}] or [la̤b]. The source for the murmured vowel in these cases is either initial h or the aspirated release of stop. This is the basis for Pandit's interpretation.

II.2.64. Problem in the analysis.

The interpretation proposed by Pandit is, however, still incomplete in the sense that it does not take care of some problems. It seems to me that it needs some significant modifications. Pandit does not set up the consonant h either as a phoneme, or as a variant; nor does he see any

need for doing so. In fact, there is no discussion in his writings on the status of the consonant h. However, it is clear from his statements that he considers the intervocalic h to have merged completely with the vowel. Moreover, he stated that murmured vowels do not occur before pause. This seems to indicate that he considers words like [sah] to end in h, but this is not stated overtly (see section II.2.63 for Pandit's interpretation). As stated by me in section II.2.61, h is observed to occur as a consonant in all positions. The fact that h occurs as a consonant in Gujarati cannot be overlooked or neglected, and one must take care of this fact in the interpretation. If h varies freely with murmur as Pandit seems to suggest, it does not prevent an interpretation of murmur as a vowel combined with h. On the contrary, it supports that analysis. The analysis is also possible if h appears in some positions and murmured vowels in others. But it does not seem to be as simple as that.

II.2.65. The possible solution.

The problem is complicated by the fact that Standard Gujarati is not a completely homogeneous language. There are variations according to the dialectal background of the speakers. Murmured vowels are most stable in the Eastern part of the country (thus in Gujarat proper), whereas many Western dialects do not have murmured vowels. In these dialects h is pronounced initially and finally, whereas medial h has normally disappeared, but leaving the vowels as clear vowels. Medial h is, however, kept in some (often learned) words. In my own dialect (Halari), there are no murmured vowels, but as I came to Ahmedabad as a child, I have acquired

stops like labh. The informants used in my investigation of vowels in Gujarati (see Chapter III) spoke a similar type of Standard Gujarati. The most confusing fact is, however, that I - and most speakers of Standard Gujarati whom I know - speak h rather consistently, also in medial position, in a number of words like hahakar, saheb, həri, ɒahyat, etc. Many of these words are either interjections of learned words, taken over from Sanskrit or Urdu, and it is not possible to find direct minimal pairs showing an opposition between murmured vowel and clear vowel + h. So perhaps these words may be considered to form a special layer of the vocabulary. Although this is not quite clear, there are so many good reasons for considering murmured vowels as combinations of clear vowels + h, that this solution seems to be the most attractive one. But further investigations of the actual pronunciations are needed. Pandit may have had other types of Standard Gujarati in mind.

We thus propose to set up a phoneme /h/ with the following variants:

1. [h] voiced glottal fricative; it occurs in (a) initial and (b) intervocalic position;
2. [h̥] voiceless glottal fricative occurring in final position;
3. [^{h}] aspirated release of stops, occurring after stops; it is voiced or voiceless according to the preceding stop;
4. [..] murmur, pronounced simultaneously with the vowel, occurring before a consonant (e.g.bə̤r, po̤r) and, in free variation with [h], [h̥], and [^{h}] in the first three positions (with

Pandit (1965) considers it to be a semi-vowel, although he has not defined it. Cardona (1965) does the same. Hockett (1955:75); 1958:94) allows semi-vowels to be included in the category of vowels if they occur as a peak nucleus or peak sattelite, and not as a margin. Trager and Smith (1957:21-22) call English /h/ a semi-vowel. Neither Hockett, nor Trager and Smith discuss a structural situation similar to that of Gujarati. Similarly, Roman Jakobson considers h to be a glide, like y and w. Probably h may be interpreted differently in different languages. In Gujarati there are no reasons against considering it as a semi-vowel.

II.3.1. Theory of distinctive features.

We have posited 30 phonemes for Gujarati. Now we shall try to describe them according to the theory of distinctive features set forth by Roman Jakobson.

II.3.21. The theory in brief.

Although the term 'distinctive feature' is often used by American structuralists following Bloomfield (1933:77-80), they do not use them in the structural description of language. In the Prague school Trubetzkoy (1939) prepared a comprehensive taxonomy of the distinctive multidimensional oppositions. They are regarded as classificational dimensions, which are used to arrange phonemes of a language into a system. For

instance, in the opposition /p/, /b/ in Gujarati, /b/ has voicing while /p/ lacks it. Not only this, but also the opposition between the two phonemes could be characterized as bilateral, proportional, and privative.

Jakobson's distinctive feature theory no longer regards the distinctive properties as merely classificational and multidimensional. It is believed that thay are components and are thus minimal linguistic units. Hence, his theory is a significant development of the Prague school phonology. 'The distinctive features are the ultimate distinctive entities of language since no one of them can be broken down into smaller linquistic units. The distinctive features combined into one simultaneous bundle form a phoneme.' (Jakobson et al. 1952:3). Another basic principle is that these components are to be described generally in terms of binary opposition (cf. II.3.22).

The theory further assumes that a universal set of distinctive features should be set up to describe all languages, and their numbers should be kept as low as possible. Out of this stock, each language to be analysed will use a restricted number of features. This is necessary for the sake of economy and simplicity of the description. Thus for each language, one has to first set up the phonemes and then to analyze them into features. Thus, a phonological matrix has to be set up with phonemes marked by their distinctive features as + or -. Some features depend on the environment. They are thus concomitant phenomena. Still, they might perhaps be needed for perception. These non-distinctive features are <u>redundant features</u>, and marked by zero in the phonological matrix. Take, for instance, Gujarati /t/, /d/, and /n/ and the features <u>voicing</u> and <u>nasality</u>:

	t	d	n
voice	-	+	0
nasality	-	-	+

If we add /s/ and the feature strident, the matrix will be:

	t	d	n	s
voice	-	+	0	0
nasality	-	-	+	0
strident	-	-	0	+

In addition to this feature dichotomy, another significant contribution of this theory is its attempt to combine articulatory, acoustic, and auditory features, and the auditory aspect is stressed. Jakobson (1962:488) justifies this as follows: 'The closer we are to the destination of the message, the more accurately we can guage the information contained in the sound chain.' This determines the operational hierarchy of levels in their decreasing pertinence: perceptual, aural, acoustical and motor (the latter carrying no direct information to the receiver except for the sporadic help of lip-reading.

When the theory was first presented in Jakobson et al. (1952), the feature description was articulatory, acoustical, and auditory. Jakobson and Halle (1956) do not give auditory definitions. This may be due to the fact that 'The distinctive features have been portrayed only on the motor and on the acoustic level, because these are the only two aspects for which we so far possess detailed information.' (Jakobson 1962:489)

As we just mentioned above, the distinctive feature theory was presented in Jakobson et al. (1952); it was modified in Jakobson and Halle (1956). A

11.3.22. The features.

The distinctive features of phonemes are described in binary oppositions. The information theory, as it is held by the communication theoreticians, says that the listener always gets a message with two choices out of which he has to select one. Thus, the listener's code is binary, according to the information theory. This view is adopted by Jakobson, Halle, and Fant (1952) as a fundamental principle in phonological analysis (cf. also Jakobson and Halle (1968:442-445).

Thus Gujarati /p/ and /b/ are described by the feature [+voice] or [-voice]. Generally these dichotomies are minimal. The same set of features describes vowels and consonants.

Our of twelve distinctive feature oppositions said to be inherent to the language and, hence, universal, each language utilizes a limited number to describe its phonemes: (1) Vocalic/Non-vocalic, (2) Consonantal/Non-consonantal, (3) Nasal/Non-nasal, (4) Compact/Diffuse, (5) Abrupt/Continuant, (6) Strident/Non-strident, (7) Checked/Unchecked, (8) Voice/Voiceless, (9) Tense/Lax, (10) Grave/Acute, (11) Flat/Non-flat, (12) Sharp/Non-sharp.

For the articulatory and acoustical definitions of the features, see Jakobson and Halle (1968). It is clear from the feature specifications that they refer to the manner of articulation and place of articulation of phonemes. The opposition Compact/Diffuse refers to the high and low (or open and narrow) phonemes, while the opposition Grave/Acute describes

the back and front (or rounded/unrounded) phonemes.

II.3.3. Distinctive features of Gujarati phonemes.

II.3.31 Four major classes.

The first two feature classes, Vocalic/Non-vocalic and Consonantal/Non-consonantal, may be said to be the features which make a basic distinction between two major classes of phonemes: vowels and consonants. However, these two feature oppositions also help us in distinguishing two other classes of phonemes: liquids and glides:

Vowels	Cons.	Glides	Liquids
+voc.	+cons.	-cons.	+cons.
-cons.	-voc.	-voc.	+voc.
i, e, E, etc.	stops, fricat., nasals	y, ʋ, h	r, l, ɭ

II.3.32. The vowels.

We have separated two major classes of Gujarati phonemes by using two major dichotomous oppositions. Now we need to make further distinctions in vowels. Table II.1 shows the feature matrix of Gujarati vowels. [The zeros are indicated by open space.]

Vocalic/ Non-vocalic	+	+	+	+	+	+	+	+
Consonantal/ Non-consonantal	-	-	-	-	-	-	-	-
Compact/Diffuse	-	+	+	+	+	-	-	+
Grave/Acute	-	-	-	+	+	+	+	+
Tense/Lax		-	+	-	+			
Flat/Non-flat				+	+	+	-	-

The feature Compact/Diffuse is meant to separate high vowels from mid and low vowels. (It is also used to distinguish back consonants and front consonants.) Thus, we are able to distinguish i and u from e, E, o, and O. Also ə is distinguished from a. We have just stated that a is +compact and ə is -compact (i.e. +Diffuse). This may be said only relatively (cf. the formant charts in III). It must be mentioned, however, that all feature specifications are relative in the distinctive feature theory. For instance, phoneme /u/ and /i/ are -Compact in relation to /o/, and /e/ respectively.

Now a has to be distinguished from other +Compact vowels e, E, o, O; ə also has to be separated from other -Compact vowels i and u. For this we employ the opposition Grave/Acute. The vowels /u, o, O, a, / are +Grave, and the front vowels /i, e, E/ are -Grave. (As for consonants, the distinction is made between the peripheral and medial consonants.

E, and o from O. [illegible]

self and most of my informants, who do not distinguish between e-E and o-O (see II.2.22 and II.2.23), we do not have any problem to separate them. Table I will distinguish them clearly, if we remove E and O.]

The three degrees of aperture of Gujarati vowels cannot be described quite satisfactorily, but it is possible to find some solutions. The vowels e and E, and o and O may be distincuished from each other in more than one way. We may describe i as -Compact, E as +Compact, and e as ±Compact. However, this method is generally not used nowadays. Although it describes the three degrees of aperture, it still is confusing to see a phoneme with both positive and negative features. Jakobson also suggested to solve the problems by assuming a further dichotomy: tense/lax. (For detailed discussion, cf. Fischer-Jørgensen 1975, p. 148-149.) By using this opposition, one may describe e as lax and E as relatively tense. The same applies to o,O.

Looking at the formant frequency charts of my informants, I found the vowel loop area for the vowel e somewhat more centrally located than for E. This might indicate that e is lax or -tense in relation to E. So we can interpret E as +tense and e as -tense.

None of my informants makes a consistent distinction between o and O. However, other speakers do distinguish them, and hence we have to include them in our analysis. A similar distinction may also be made between them: O as +tense, and o as -tense (Table II.1).

cf. also p. 431 for Grave/Non-grave, and Acute/Non-acute). According to this solution, the vowels E and O are +Compact and -Diffuse, while e and o are [-Diffuse, -Compact] (Table II.2).

TABLE II.2

Alternative feature matrix for Gujarati vowels

	i	e	E	o	O	u	ə	a
Vocalic/ Non-vocalic	+	+	+	+	+	+	+	+
Consonantal/ Non-consonantal	-	-	-	-	-	-	-	-
Compact/ Non-compact	-	-	+	-	+	-	-	+
Diffuse/ Non-diffuse	+	-	-	-	-	+	+	-
Grave/Acute	-	-	-	+	+	+	+	+
Flat/Non-flat				+	+	+	-	-

In table II.2, a, ə are characterized as +Grave and distinguished from u, o, O by being Non-flat. In a way, this may be true for English (see Jakobson et al. 1952, p. 43), but perhaps not so much for Gujarati. The formant chart for both vowels indicates (cf. III) that they are central and not really back (+Grave). They may, therefore, be interpreted as -Grave and -Acute. But this also cannot be done,

and Halle 1968, p. 431). We have therefore, [illegible] terpret ə and a as +Grave.

In any case, we do not need more than six binary oppositions to describe the distinctive features of eight Gujarati vowels (or 4, if the category of vowel is taken separately).

A comment about splitting up an autonomous dichotomous scale of distinctive feature into two autonomous scales is perhaps necessary. This type of division is, of course, artificial, and is adopted only for convenience or as a way out if one wishes to keep the features binary. Moreover, it will not work for the languages which have four degrees of aperture (cf. Fischer-Jørgensen 1975, p. 149).

II.3.3. The liquids and glides.

Gujarati has three liquids: r, l, and l̤. It also has three glides: y, ʋ, h. According to Jakobson and Halle (1968), glides are -Vocalic and -Consonantal. Their reasons are not clear. To Fant (1967) it is arbitrary. Fischer-Jørgensen (1957, p. 157) indicates that y, w can also be considered as +Vocalic and +Consonantal, like liquids.

The description of h and ʔ is also not convincing, according to her: 'From an articulatory point of view they must be +Vocalic, since they are articulated without any constriction in the buccal tract.' As rightly stated by her, both h and glottal stop are generally considered to be

consonants.

The analysis of y, w (and perhaps also of h, ʔ) is not clear, and awaits further investigation.

Table II.4 shows the liquids and glides of Gujarati according to their distinctive features. l and l̤ are distinguished by the feature Flat, r and l are distinguished by the feature Abrupt, y and ʋ by the feature Grave, and h is distinguished from all by the feature +Tense.

TABLE II.3

Feature matrix for glides and liquids

	r	l	l̤	y	ʋ	h
Vocalic	+	+	+	-	-	-
Consonantal	+	+	+	-	-	-
Abrupt	+	-	-			
Grave				-	+	
Tense	-	-	-	-	-	+
Flat		-	+			

Jakobson et al. (1952, p. 43) defines h as +tense in contradistinction to #, which is -tense. In Gujarati, however, we are interpreting h as +tense without having any such phoneme as /#/ having values opposite to /h/. This is not very convincing, but that seems to be the only alternative.

passage. We have four nasal phonemes in Gujarati: /m, n, n̤, N/, which are distinguished from the non-nasal phonemes by the feature +Nasalized. Table II.5 shows their distinctive feature matrix.

TABLE II.4

Feature matrix for Gujarati nasals

	m	n	n̤	N
Vocalic	-	-	-	-
Consonantal	+	+	+	+
Nasal	+	+	+	+
Compact	-	-	-	+
Grave	+	-		
Flat	-	-	+	-

We use the feature +Compact to separate N from m, n, and n̤. Jakobson accepts nasalized vowels as phonemes in his distinctive feature theory. However, in our phonemic interpretation of Gujarati vowels (II.2.51) we have treated them as V+N rather than unit phonemes. There is no discussion or indication in Jakobson's system as to what should be the distinctive features of phonemes like Gujarati /N/. Since two of the allophones of /N/ are the palatal [n] and velar [n̤], I have defined it as +Compact.

II.3.51. Other classes of consonants.

Table II.5 presents Gujarati consonant phonemes (including nasals, liquids, and glides) according to their distinctive feature oppositions.

The feature Abrupt/Continuant is used to separate stop consonants from sibilants. The following chart shows the consonants and the features specifying them:

Palatals, velars:	+Compact	:	Labials, dentals, alveolars:	-Compact
Labials, velars:	+Grave	:	Palatals, dentals, alveolars:	-Grave
Retroflexes, (nasals, stops, laterals):	+Flat	:	Dentals	-Flat

The stop consonants have silence followed by a noise burst in their spectrum. So acoustically they are defined as +Abrupt. r is abrupt, perhaps because of the presence of a momentary closure (Gujarati r is generally one tap r).

II.3.52. Retroflex stops.

The feature opposition Flat/Non-flat attempts to define three types of phonemic classes: rounded phonemes, pharyngealized phonemes, and the retroflex phonemes. Flattening produced by lip-rounding is the characteristic of rounded vowels. The pharyngealized (or emphatic) consonants

TABLE II.5

Feature Matrix for Gujarati Consonants

	p	b	t	d	ṭ	ḍ	c	j	k	g	r	l	ḷ	m	n	ṇ	N	s	ś	y	v	h
Vocalic/Non-vocalic	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-
Consonantal/Non-consonantal	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-
Nasal/Non-nasal	-	-	-	-	-	-	-	-	-	-				+	+	+	+					
Compact/Diffuse	-	-	-	-	-	-	+	+	+	+				-	-		+	-	+			
Abrupt/Non-abrupt	+	+	+	+	+	+	+	+	+	+	+	-	-					-	-	-	-	-
Voiced/Voiceless	-	+	-	+	-	+	-	+	-	+												
Tense/Lax																				-	-	+
Grave/Acute	+	±	-	-	-	-	-	-	+	+				+	-	-		-	-	-	+	
Flat/Non-flat			-	-	+	+						-	+	-	-	+	-					

flex and dental consonants, characteristic in particular of various languages in India, is another manifestation of the same opposition (see Fig. 8): both the contraction of the pharynx and the elongation of the resonating cavity take place in producing emphatic as well as retroflex consonants, but for the former the first process, and for the latter the second seems to be of greater pertinence.' All of these three share one common feature: the flat consonant displays weakening of high frequency components. Figure 8 of the above referred book shows that the Circassian and Arabic flat consonants affect the second formant of the following vowel in a downward direction, while the retroflex consonants affect the third formant of the following vowel in the downward direction.

I think the definition of the retroflex consonants is not very clear, and they need to be well defined. For further discussion, see Chapter IV.

II.3.53. Aspirated stops.

Jakobson and Halle (1968, p. 441) interpret the aspirated stop consonants as unit phonemes (e.g. they transcribe /dh/ as /d$^{\epsilon}$/) and consider tenseness as one of their distinctive features. We interpret the aspirated stops as clusters of two phonemes, one of which is /h/, and define tenseness as its distinctive feature. This is economical. There is, however, no discussion in any of Jakobson's writings on the breathy or murmured vowels. They are also clusters in our analysis and give no problem in distinctive feature theory.

Out of a stock of twelve permissible dichotomous opoositions Gujarati uses nine to define and describe its thirty phonemes as posited by us. We have some difficulty with Compact/Diffuse for describing e, E, o, O, and with Grave/Acute for separating a and ə from u, o, O. We use the features tense/lax and flat/non-flat to do so. Alternatively, it is also possible to do so by splitting the features Compact/Diffise into Compact/Non-compact. This seems to be rather a matter of convenience, as there are not convincing reasons for doing so. The problem in using two autonomous features is that one common phonetic description has to be used to be applied to both. The new acoustic description of Compact/Non-compact and Diffuse/Non-diffuse is indicated in Jakobson and Hall (1968, p. 430); still, they need to be properly defined articulatorily and acoustically. Fischer-Jørgensen (1975, p. 149) considers this to be 'a purely descriptive trick.'

It would perhaps be a good idea to split up the feature flat/non-flat into more than one features:

II.3.7. Distinctive features in generative phonology.

The theory of distinctive features has given significant contribution to the development of the structural phonology on one hand, and generative phonology on the other. The phoneme and phonemic level are no more recognized in generative phonology. The distinctive features are,

TABLE II.6

Feature Matrix for Gujarati Phonemes

	i	e	E	o	0	u	ə	a	p	b	t	d	ṭ	ḍ	c	j	k	g	r	l	ḷ	m	n	ṇ	N
Vocalic	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-
Consonantal	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Compact	-	+	+	+	+	-	-	+	-	-	-	-	-	-	+	+	+	+				-	-	-	+
Grave	-	-	-	+	+	+	+	+	+	+	-	-	-	-	-	-	+	+				+	-	-	
Tense		-	+	-	+																				
Flat				+	+	+	-	-					-	-	+	+				-	+	-	-	+	-
Nasalized									-	-	-	-	-	-	-	-	-	-				+	+	+	+
Abrupt									+	+	+	+	+	+	+	+	+	+	+	-	-				
Voiced									-	+	-	+	-	+	-	+	-	+							

however, used to describe the phonological segments by + and - matrix, i.e. by binary oppositions. On the phonetic level, however, multi-dimensional oppositions are permitted.

Jakobson's +diffuse vowels are +high, +compact vowels are +low, and +grave vowels are +back. Moreover, the feature +anterior is used to describe the diffuse consonants. The feature +coronal described the +anterior consonants with the feature -grave (dentals), while the feature -coronal described the anterior consonants having the +grave feature (labials). However, the palatal consonants, which are -grave in the distinctive feature theory, are considered to be -coronal. The feature +high described palatals and velars; the feature +back will separate velars from palatals, which are -back. The velars and palatals are [-anterior, -coronal], while the dentals are [+anterior, +coronal], and the labials are [+anterior] and [-coronal].

A new feature sonorant/non-sonorant (obstruent) is introduced to simplify the definitions of Vocalic/Non-vocalic and Consonantal/Non-Consonantal. This is also meant to include vowels, glides, nasals, and liquids in one class, i.e. +sonorant, and stops, fricatives, and affricates into another class. By this arrangement, the glides are:

$$\begin{bmatrix} +\text{sonorant} \\ -\text{vocalic} \\ -\text{consonantal} \end{bmatrix}$$

and the liquids are:

$$\begin{bmatrix} +\text{sonorant} \\ +\text{vocalic} \\ +\text{consonantal} \end{bmatrix}$$

The feature opposition Distributed/Non-distributed is set up to describe the retroflex consonants. The dentals are now:

$$\begin{bmatrix} +\text{anterior} \\ +\text{distributed} \end{bmatrix}$$

and the retroflexes are:

$$\begin{bmatrix} +\text{anterior} \\ -\text{distributed} \end{bmatrix}$$

Another feature is added to the system to take care of aspirated stops and murmured vowels as phonemes, or we interpret them as made of two underlying phonological forms (i.e. stop + h, or vowel + h), we may define them by using the features [+ low] and [+heightened subglottal pressure] (cf. Chomsky and Halle, pp. 307 and 321). Note that we have used the feature [+tense] for the same purpose (Table II.7).

II.3.81. The feature system of Peter Ladefoged.

Ladefoged (1971b) proposes a new system of general phonetic features. His features are mutli-dimensional on the phonetic level, as they are in generative phonology. Also on the systematic phonemic level some features are multi-dimensional. He sets up a number of phonetically definable steps, and denotes them by relative numbers, 0, 1, 2, etc. The

multi-dimensional feature will be specified by these numbers. Take, for instance, his feature glottal stricture. It is specified as follows: (1) glottal stop, (2) creak, (3) creaky voice, (4) tense (soft) voice, (5) voice, (6) lax (slack) voice, (7) murmur, (8) breathy voice, (9) voiceless.

Another feature is voice onset: (1) voicing throughout articulation, (2) voicing during part of articulation, (3) voicing starts immediately after, (4) voicing starts shortly after, (5) voicing starts considerably later.

Ladefoged (1971b, pp. 8, 12-14, 96-97) considers the voiced aspirated stops (of Hindi) to be murmured stops. He defines aspiration as 'a brief period of voicelessness during and immediately after the release of an articulatory stricture'. The voiceless aspirates, according to him, meet this requirement, but not the so-called voiced aspirates. They do not have normal voicing during their closure and aspiration, but murmur. Normal voicing of bh, etc. does not start until the start of next vowel; so they should be considered as murmured stops rather than aspirated stops. Gujarati stops, if interpreted as unit phonemes, will be specified in Ladefoged's feature system as follows:

	ph	p	b̤	b
glottal stricture	0	0	1	2
voice onset	2	1	2	0

b̤ = bh.

The number value, which is of course arbitrary and relative in his

system, is 2, both for ph and b̤, as the voicing does not start for b̤ until a later stage.

We have interpreted h as a phoneme and aspirated stops and murmured vowels as made up of two phonemes. Ladefoged considers h and glottal catch, (ʔ), both as true consonants and not glides.

Some of the accepted features in Ladefoged's classificatory matrix for systematic phonetics are: stop, rate (a ballistic rate is tap), laterality, height (i.e. the tongue-height), backness (front, etc.), tenseness, apicality, fricative, and articulatory place. It is not quite clear how the retroflex consonants will be characterized in his system. Perhaps by the following features: stop, apical, post-alveolar.

CHAPTER III

ACOUSTIC ANALYSIS OF CLEAR, NASALIZED, AND MURMURED VOWELS

III.1. General remarks.

In this chapter and in the following chapter we will give a phonetic analysis of some of the peculiar features of Gujarati which were described from a phonological point of view in Chapter II. Such an analysis may be interesting in itself. Moreover, although it is true that 'phonemes cannot be found in curves' (Fischer-Jørgensen 1957, p. 478), it is also true that an instrumental analysis may contribute to the phonetic description of phonological features set up in a more intuitive way, and thus contribute to deciding which features to use in the analysis of given phonemes. Compare, for instance, the discussion of the distinctive feature analysis of a and ə in Chapter II.

The most characteristic feature of Gujarati vowels is the presence of phonologically distinctive nasality and murmur. As for the phonological interpretation it was proposed in Chapter II to analyse nasalized vowels as vowel + N, and murmured vowels as vowel + h. However, phonetically they are unit sounds, and the acoustic analysis given in this chapter must be based on this fact.

This is an abbreviated and revised report on a earlier research project undertaken by me at the Institute of Phonetics, University of Copenhagen, Denmark in 1966-67 (see R. Dave 1967, pp. 1-30, and R. Dave

1968, pp. 119-127). The main purpose of the project was to undertake a comparative formant analysis of clear, nasalized, and murmured vowels. The murmured vowels have been investigated in more detail by Fischer-Jørgensen (1967.

III.2. Informants.

III.2.11. Gujarati speakers in Copenhagen.

It was difficult to find Gujarati speakers in Copenhagen, but it was much more difficult to find an informant who had murmured vowels in his own dialect as phonemically different from clear vowels. However, SK seems to have this feature in his speech. The other two informants had murmured vowels as a possible pronunciation of the words in which SK had murmured vowels, but in free variation with clear vowels medially, and with h + vowel initially and vowel + h finally.

III.2.12. Bio-data of the informants.

The bio-data of the informants is as follows:

Informant	Birthplace	Year of Birth	
SK	Surat, Gujarat	1938	In Copenhagen 1965-66.
RT	Bombay	1941	In Copenhagen since 1965.
RD	Pad-dhari, Gujarat	1928	In Copenhagen 1965-68; in USA since 1968; writer of the present thesis.

III.3. The Corpus.

Two lists were prepared in June, 1966. List 1 contained examples of clear and nasalized vowels. This list included words as well as one example of each vowel spoken in isolation. List 2 contained examples of clear and murmured vowels in words, phrases, and sentences. Isolated murmured vowels were not pronounced (see Appendix A for the lists).

Generally vowels spoken in syllables and words are preferred to isolated ones for 'untrained voices' (Potter and Peterson 1948, p. 531). They are considered to be 'especially advantageous when dealing with lay speakers and listeners' (Potter and Steinberg 1950, p. 809).

We have already mentioned that e and E, and o and 0 are separate phonemes in Gujarati, although they are found in opposition only in initial syllables, and not in all dialects (see II.2.23). Varying degrees of openness for e-E and o-0 have been noticed by me in the speech of my informants. RD has only six vowels in his speech (i e a o u ə). SK and RT have a constant more open vowel in mEk and m̤Ek than in the other words. No distinction of o and 0 was found for these formants. Therefore, only e and o have been used in the transcription, except for mEk, and m̤Ek.

III.3.1. List 1: Clear and nasalized vowels.

Consonants with different places of articulation have different 'loci', and they influence the vowel formants in different ways. This has been discussed by Potter-Kopp-Green (1947), Fant (1958), Fischer-Jørgensen (1957), and others. Care was taken to select consonants which

have a minimum influence on the vowel formants. Generally front vowels, particularly close front vowels, show extensive transitions with labials, and smaller transitions with dentals, whereas back vowels, particularly close back vowels, show extensive transitions in connection with dentals and palatals, and smaller transitions with labials. In combination with velars the extent of transitions differ from language to language according to the degree of assimilation and the place of articulation.

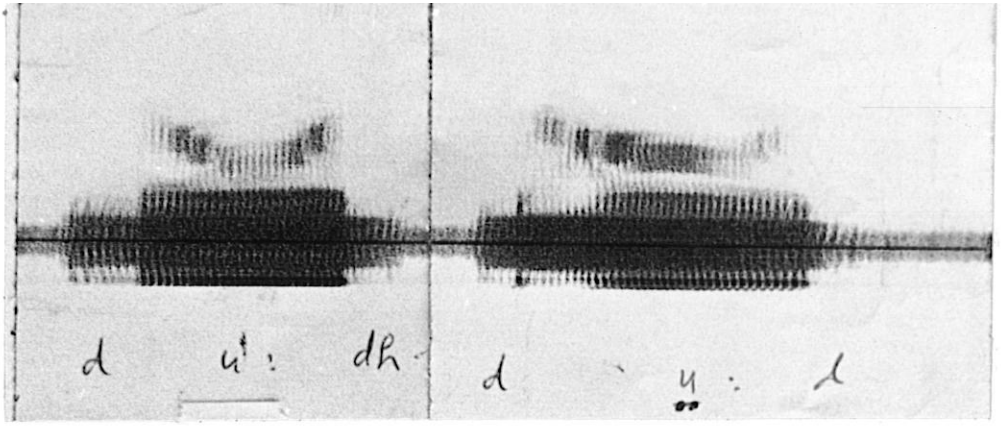
Thus, combinations of dental consonants with front vowels, and labials with back vowels, have generally been preferred in list 1. Whenever this was not possible, h or velar or l was selected.

III.3.2. List 2. Clear and murmured vowels.

It became difficult to follow the above mentioned principle in case of murmured vowels.

It was found to be more important to find such commutable pairs whose pronunciation was familiar to the informants. Therefore, I had to accept such examples as [dudh], [d̤ud], [d̤o̤r], [bi], and [b̤i] with strong formant bendings, and words with nasal consonants such as [mek] and [mor], which often show a certain degree of nasalization of vowels. This explains the great dispersion of the formant frequencies in the vowels of list II (see the charts). The fact that [u] of list 2 has a clearly higher F_2 than [u] of list 1 is due to its position between two dentals ([dudh]). See Fig. III.1. It was not possible to find any minimal pair of clear and murmured [u]. Therefore, the words [dudh] and [d̤ud], which are only variants, had to be included in the text.

It should be noted that the pronunciation of murmured [ṳ] seemed



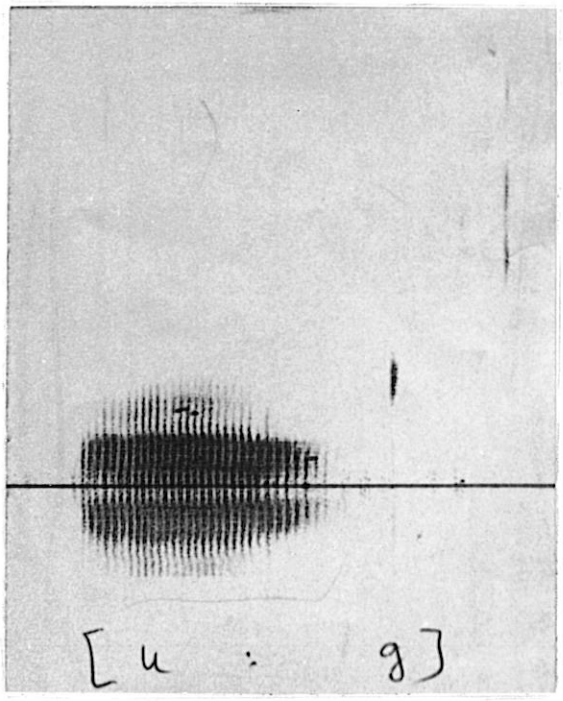


Figure III.1. Spectrograms of dudh, dud, and ug.

were taken only as specimens.

The words were pronounced in pairs by RD and SK, but twice in reversed order to counterbalance any effect of intonation. Moreover, they were spoken in isolation and in sentences (for the word lists, see Appendix I).

III.4. Technical details.

III.4.1. Studio.

The recordings of SK and RD were made in the recording room of the Technical High School of Copenhagen, Denmark, in June 1966. The recordings of RT were made in the studio of the Institute of Phonetics, University of Copenhagen, in January 1967. Both studios were reasonably anechoic.

III.4.2. The apparatus.

Two Lyrec tape-recorders of the professional type were used for the tape recording. The recordings were made on Scotch magnetic tape with a speed of 7-1/2 inches per second. The acoustic analysis was made on the basis of spectrographic recordings.

The sound spectrograph is one of the basic instruments for acoustic analysis of speech. The first sound spectrograph was constructed in the Bell Telephone Laboratories. It was made commercially available by the

tion were made on a Kay Electric sonagraph. The words to be investigated are played over from the tape to a magnetic disc which can store a speech sample of 2.4 seconds' duration. Electrically sensitive paper is wrapped around a drum mounted on the disc and rotating with the disc.

When the disc is rotating the sample is repeated over and over again. It is picked up by a scanning head and passed through a band-pass filter with movable center frequency onto a stylus which moves upwards and burns a signal into the electrically sensitive paper. The vertical movement of the stylus is synchronized with the change of center frequency of the filter, so that low frequency components of the sample are recorded at the bottom of the paper and higher frequency components gradually higher up on the paper.

The graphical picture obtained is called a spectrogram. It shows time horizontally and frequency vertically, whereas intensity is indicated more roughly by the degree of blackness. It is possible to use either a "narrow band filter," which is 45 Hz wide producing a display in which the single harmonics are seen as horizontal streaks, or a wide band filter, which is 300 Hz wide and which records more than one harmonic at a time, displaying the regions of stronger energy as horizontal black bands (see Fig. III.2). A more accurate display of the intensity of the harmonics can be obtained by means of the "sectioner." A "section" gives a display showing frequency versus intensity at a given moment. Sections can be taken both with the wide and the narrow filter

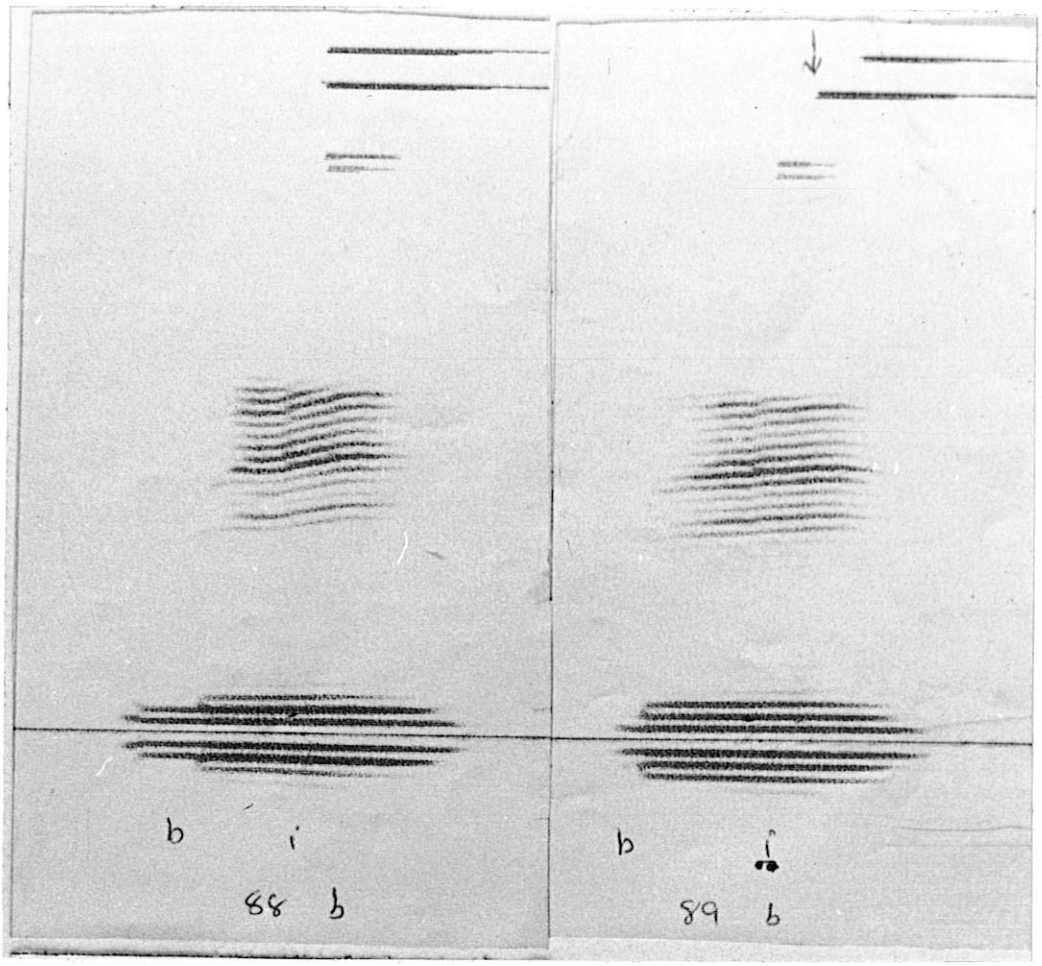


Figure III.2. Spectrograms of bi and bi.

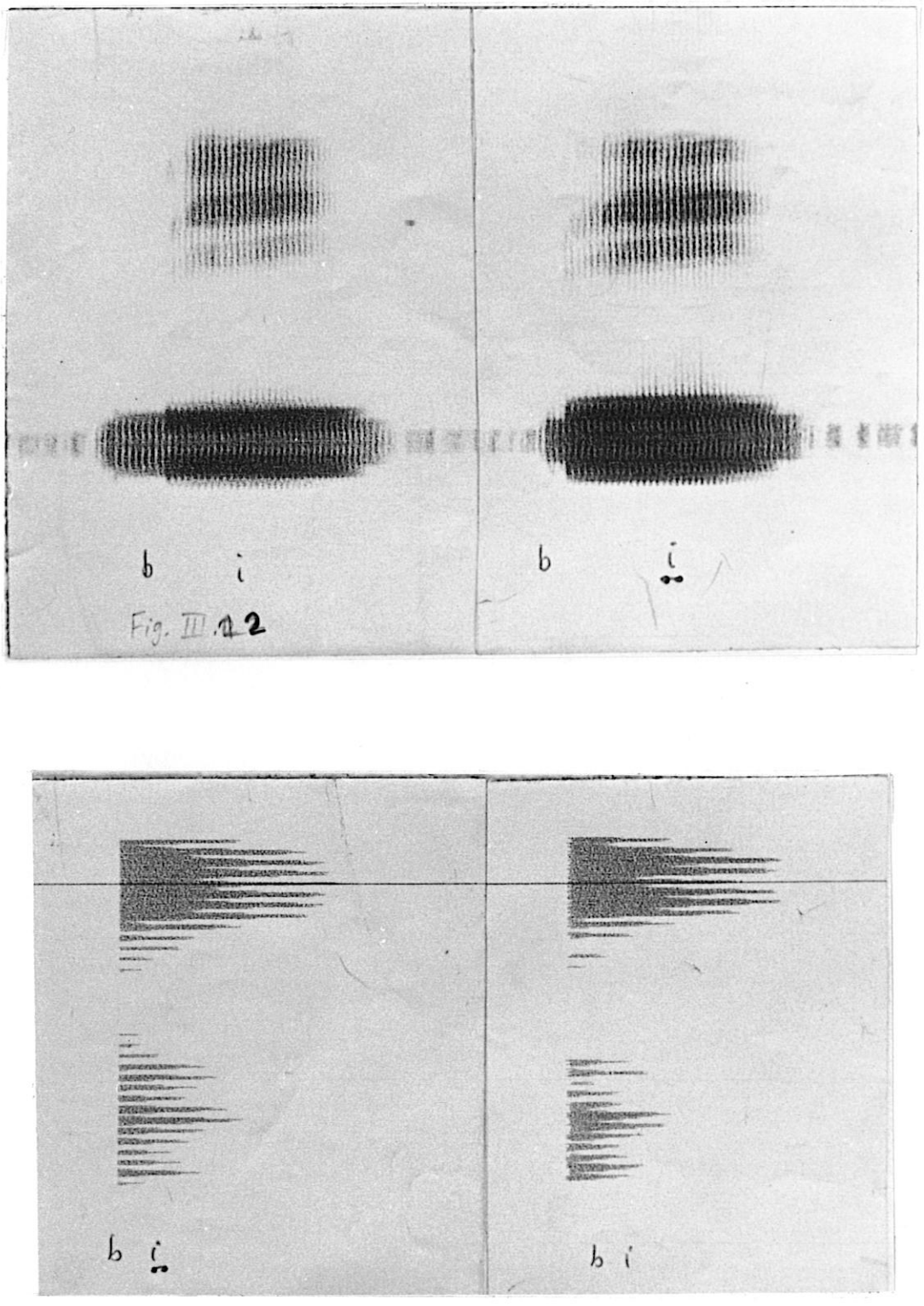


Figure III.2. Spectrograms of bi and bi̤.

major peaks of the spectrum are the main correlates of the so-called formants (see below). The sound spectrograph can be used for measurements of duration, of fundamental frequency, and of the frequency pattern (the formant pattern) of the sound. By means of a special device it is also possible to get a curve of the overall intensity and its change in time.

The spectrograph used in the present investigation was a Kay Electric sonagraph purchased in 1953. This instrument was rather old and worn out; its amplitude was insufficient, and its high shaping gave no high frequency emphasis. Therefore, an extra amplifier with high frequency emphasis and damping of the bass was inserted between the tape recorder and the sonagraph. This gave good spectrograms for RD and SK, whose voices had a rather strong bass emphasis, but for RT less bass damping would have been desirable. We preferred, however, to keep the same setting of the instrument.

III.4.3. Number of spectrograms.

Spectrograms were taken of one reading only for each person, or when necessary (because of pronunciation with h or without murmur), of a corresponding number of words from different readings (this was particularly the case for RT). From list I the number of samples taken was generally between 5 and 9 for each vowel. From list II, the number was at least 4-5, and often 8-12. At least three spectrograms were taken of each sample: wide band, narrow band, and narrow band section. In all,

2274 spectrograms were taken and measured.

III.4.4. Measurement of the fundamental.

The fundamental frequency was measured on the section (when possible, by dividing by ten the distance between the first and the eleventh harmonic). This measurement was primarily intended as a help for the measurement of formant 1, whose peak frequency can be indicated more exactly when the frequency of the harmonics is known. As most of the words were spoken with rising intonation, and as the section was not taken at exactly the same place in different words (generally in the middle), its value as an indication of the pitch level is restricted.

III.4.5. Formant measurements.

'The lack of definition of a formant remains, and very probably it is not possible to provide a single definition which is of use to the investigator who is examining spectrographic data,' says Ladefoged (1962, p. 40). We have two definitions of the term formant. A formant is generally defined as 'a frequency-region of energy concentration in the spectrum of a vowel-sound' (see Potter and Steinberg 1950, p. 811). Another definition (see Fant 1961, p. 23-24) refers to the frequency of the corresponding vocal resonance. Lindblom (1961, p. 191) also refers to the resonance frequency of the vocal tract. But we must remember that both Fant and Lindblom point out at the same time that the differences between the peak frequency of the acoustic spectrum envelope and the corresponding resonance frequency of the vocal tract are negligible.

particularly when they are very close or very low (in these cases they are often asymmetric), or when they are very weak.

But in spite of these difficulties, it is true, as Ladefoged (1962, p. 39) says that the specification in terms of formants still seems to give the simplest and most adequate description of vowels.

In our investigation, we have determined the formant frequency (F-frequency) by its energy maximum. It was determined by a comparison between the wide band, the narrow band, and the narrow band section spectrograms and was mainly based on the latter two types of spectrogram, whose values were very close. The peak envelope on the section was considered to be the center frequency of the formant.

III.5. Results

III.5.1. Tables. (A.1 - A.7)

The results of the acoustic measurements are given in form of tables and charts. The tables give the formant frequencies: Tables 1-7 are given in Appendix A. Tables 1-3 show the averages of the F-frequencies of clear and nasalized vowels spoken in words (list 1). Table 4 shows the measurements of isolated clear and nasalized vowels. Tables 5-7 show the averages of the formant frequencies of clear and murmured vowels (list 2).

A question mark indicates some doubt as to the location of the

is left blank when nothing was seen in the spectrogram. The number in parenthesis to the right of the measurements indicates the number of samples on which the average is based.

III.5.2. Charts.

The charts are given in Figures 5-22 (pages 73-90). They show the frequencies of formant one (F_1) and formant two (F_2) in a two-dimensional plot. Charts number 1-3 are prepared from the averages; charts 4-6 show F_1 versus F_2 areas of the individual clear and nasalized vowels of each informant (list I).

Each point plotted in the charts of single examples indicates one example of each vowel. The scale number on the charts indicate frequency in Herz, but the distance between the lines (and, consequently, the visual picture) corresponds to the mel scale (cf. Peterson and Barney 1942, p. 172-184).

Figures 11-13 show the frequency of formant one and formant two, based on the averages. Figures 14-16 show the F_1-F_2 areas for the clear vowels of each informant, and Figures 17-19 display the F_1-F_2 areas for the murmured vowels of each informant. As said above, each dot represents one sample of each vowel. When two or more points coincide or are very close, they have been put as close as possible to the exact frequency. See a̤ and i̤ in RD and RT (Figures 17-19).

Clear and nasalized vowels are generally clearly distinguished in

III.6. Nasalized vowels compared to clear vowels.

III.6.1. Characteristic features of the nasalized vowels.

The following features of the nasalized vowels have been observed:

(1) The Fundamental. F_o is higher for the nasalized vowels in many cases, but not always. The average F_o for i, u and a of all informants is higher than that of their oral counterparts. The value of F_o for other vowels varies from one informant to another. On the whole, the differences are small. In RT, however, the differences are clearer.

(2a) Formants one and two. Almost all investigators of nasalized vowels (see, for instance, Fant 1960, pp. 148-149, and Kongsdal Jensen 1967, pp. 59-66) have stressed that the major cues for nasalization lie in the region of F_1. 'The most pronounced spectral changes occur in the region of the first formant...The results of the physical measurements with the analog devices strongly suggest that the first formant effects may be primary cues for nasality' (House and Stevens 1956, p. 225).

Looking at the averages of our informants, all have a lower F_1 in $\tilde{u}$ than in u, and SK and RT have a slightly lower F_1 for $\tilde{i}$. All informants have considerably higher averages for F_1 in the open nasalized vowels $\tilde{E}$ and $\tilde{O}$, $\tilde{a}$ and $\tilde{\text{ə}}$, and there is no overlapping between single examples except for a and $\tilde{a}$.

House and Stevens (1956, p. 225) mention an upward shift in the center frequency of F_1 for the open nasalized vowels. Lowering of F_1 for u has not been mentioned by anybody. It may perhaps be explained by a fusion of F_1 with the nasal subformant (see discussion on subformants in (3)).

Weakening of F_1 for the open nasalized vowels is evident in the spectrograms (see Fig. III.3). This has been said to be the principal cue for nasality by Joos (1948, p. 96), Delattre (1954, pp. 103-109), House and Stevens (1956), Smith (1951), and Fant (1960, p. 159). F_1 for $\tilde{i}$ and $\tilde{u}$ is not affected.

Generally F_1 for both e and $\tilde{E}$ was difficult to measure, but F_1 for $\tilde{E}$ is much weaker and split. Often a harmonic in the area of F_1 loses its energy halfway.

F_2 for $\tilde{i}$, $\tilde{E}$, and $\tilde{O}$ is somewhat raised in all informants (this is particularly true of $\tilde{i}$, but all have a lower F_2 for $\tilde{ə}$, $\tilde{u}$ and $\tilde{a}$).

The same investigators, just referred to by us above, and who noted the weakening of F_1 for nasalized vowels, have mentioned a possibility of some amplitude reduction also for F_2. As I have not measured the intensity, it is not possible to make any statement about this.

The result of the differences in F_1-F_2 is that the nasal vowels occupy more extreme positions in the vowel charts. In order to give a clearer graphical illustration of this fact all oral (clear) vowels are connected by a full line and all nasalized vowels are connected by a broken line in charts 1-3.

(2b) Formants three and four. All informants have higher F_3 for $\tilde{i}$ than for i. F_3 for $\tilde{E}$ is also, to a certain extent, higher than F_3 for e. In

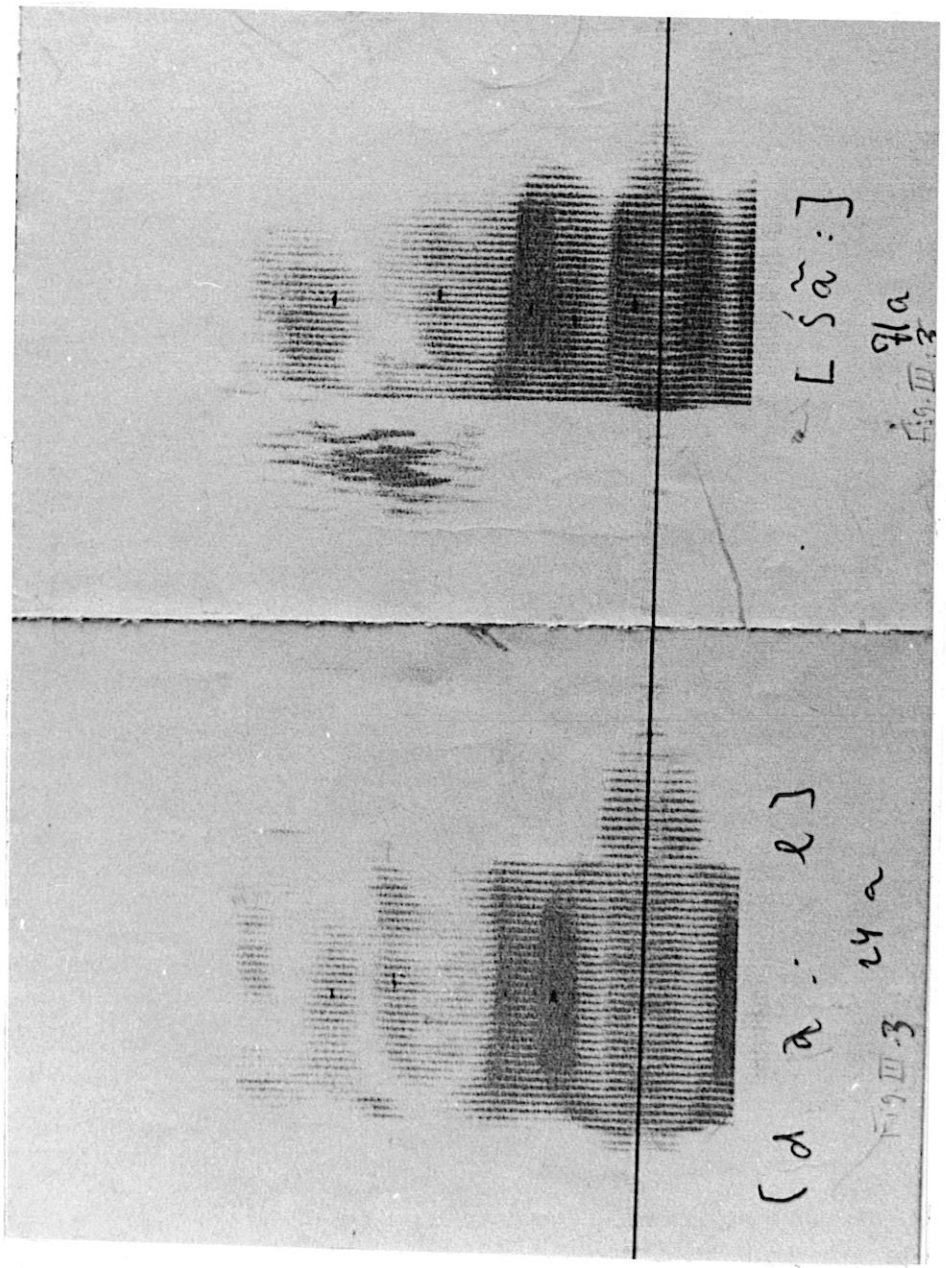


Figure III.3. Spectrograms of dal and sã̃.

few exceptions.

The exact location of F_3 and F_4 sometimes makes difficulties because the formants may be split, and there may be extra resonance. Thus, F_4 for a and $\tilde{a}$ gives uncertain measurements (Fig. III.3).

As appears from the tables, all informants have a relatively lower F_4 in a compared to F_4 of other vowels. But as a has also a formant at the same (higher) frequency as F_4 for other vowels, it would have perhaps been better to consider the lower F_4 of a as an extra formant or to consider F_4 as split up into two formants in a.

Generally, F_3 is weak for nasalized vowels, and F_4 seems to retain its energy in many cases. F_3 is sometimes so weak that it is completely eliminated. This is, however, not often the case for $\tilde{E}$. The indications about F_3 and F_4 in the literature are rather confusing. Smith (1951, p. 22) refers to a resonance between 2500 and 3500 cps. House and Stevens (1956) note a double peak in the region of the third formant. The possibility of elimination of F_3 is also mentioned (see Fant 1960, p. 155). Smith (1951) mentioned intensification of F_4. Delattre (1954) mentions lowering of F_4, while I have found it more or less raised.

(3) Subformant. The appearance of a subformant (F_s) has been said to be a secondary cue for nasality. However, it seems to be a very important one. A subformant of the open nasalized vowels seems to be at the same frequency as the first formant in the nasal conconants, and in the nasalized vowels $\tilde{i}$ and $\tilde{u}$. Hattori et. al. (1958, p. 267) believed this

to be a 'reinforcement of intensity in the region around 250 cps.'

In our spectrograms an F_s is seen in all open (Fig. III.3) nasalized vowels, with a few exceptions. RD has an F_s also in his clear vowels. But F_s for the nasalized vowels is generally found between 240-300 Hz, whereas F_s for the clear vowels is generally between 190-250 Hz. Thus, F_s for the nasalized vowels is generally somewhat higher than F_s for the clear vowels.

It was suggested (in 2a) that the lower F_1 of $\tilde{\underline{u}}$ as compared to $\underline{u}$ might be due to a fusion with the sub-formant. As the subformant has a frequency around 240-300 Hz, and as the clear $\underline{u}$ has a formant around 300 Hz, the addition of the subformant will lower the energy center, and it is difficult to distinguish the first formant from the subformant. The 'lowering' is, thus, in a sense an illusion. As for $\underline{i}$, it has always a lower F_1 than $\underline{u}$. Its formant is around 250 Hz and thus coincides completely with the subformant, and no change in center frequency appears.

(4) Zeros or anti-resonances. Hattori et al. (1958) mention the weakening of intensity at about 500 cps. as a characteristic feature of nasalization of the vowels. According to them, it may be due to the anti-resonance of the nasal cavity. Joos (1948) points to the presence of an anti-resonance at 900 cps. House and Stevens (1956) mention the possibility of a subformant around 700-800 cps., depending on the amount of damping.

A valley is seen in the spectrograms of the open nasalized vowels in the frequency range of circa 400-500 Hz (in agreement with Hattori et al.). A corresponding peak for the clear vowels is, however, not seen

It is not possible to discuss here the problems of zero, F_x and band-width, etc., as this was not included in the main purpose of my investigation.

(5) Extra formants. Appearance of extra formants has been mentioned by various research workers. Joos (1948) mentions formant 1n and 1n' above F_1, and formants 2n and 3n below F_2 and F_3, respectively. According to Smith (1951), an extra formant often appears at 1000 cps. Such components have also been noticed by me. It is not possible, however, to state their exact frequency region. Extra formants are generally irregular and inconsistent in my informants. However, their general frequency region may be said to be in the region of 1000 to 2500 cps., as stated by Hattori et al. (1958). More investigations are necessary.

(6) The following characteristics should be mentioned also in addition to those mentioned above:

(a) In nasalized vowels, increase in the band-width of F_1 is also noticed by House and Stevens (1956). I have noticed this in some cases, but have not been able to see it in all. F_1 for $\underline{\tilde{i}}$ and $\underline{\tilde{u}}$ does not seem to be affected. $\underline{\tilde{E}}$, $\underline{\tilde{a}}$, $\underline{\tilde{O}}$ and $\underline{\tilde{ə}}$ have slightly increased band-width of their F_1.

(b) House and Stevens (1956) mention one more feature of nasalization: reduction in the overall level of the vowel. This has not been

investigated by me.

III.6.2. Summary of the features.

The characteristic features of the nasalized vowels may be summarized as follows:

(1) There is no constant change in F_o; still, there is a tendency to have slightly higher F_o in the nasalized vowels.

(2a) $\tilde{E}$, $\tilde{a}$, $\tilde{O}$, $\tilde{ə}$ have a higher F_1 than E, a, O and ə, whereas $\tilde{u}$ has a lower F_1 than the F_1 of u for all informants (see, however, III.6.1 (3) above). Nasalized $\tilde{i}$ has a somewhat lower F_1 than i in SK and RT.
F_1 for $\tilde{E}$, $\tilde{a}$, $\tilde{O}$, $\tilde{ə}$ is weakened; F_2 for $\tilde{u}$ is weakened.

(2b) Higher formants are weakened. F_3 is more affected than F_4, and sometimes eliminated. F_4 tends to be raised.

(3) A sub-formant (F_s) in $\tilde{E}$, $\tilde{O}$, $\tilde{a}$ and $\tilde{ə}$ appears between 200-300 Hz.

(4) There seems to be a zero in $\tilde{E}$, $\tilde{a}$, $\tilde{O}$ and $\tilde{ə}$ between 400-500 hz.

(5) Small peaks are found at irregular frequencies.

III.7 Murmured vowels compared to clear vowels.

III.7.1. Formant frequencies.

Whereas the nasalized vowels are found to differ clearly from the clear vowels in their general formant structure, this is not the case for

Figures 14-19 the individual examples of clear and murmured vowels are plotted separately, and in Figures 11-13 and 20-22 the areas are superimposed on each other, showing complete overlapping. This means that the differences between clear and murmured vowels are not due to a change in the cavities of the upper vocal tract giving different resonance frequencies. In the nasalized vowels such a change was caused by the lowering of the velum and consequent coupling of the oral and nasal cavities. The difference between clear and murmured vowels must be mainly due to changes in the glottis giving a different source spectrum.

III.7.2. Further characteristics of murmured vowels.

As the formant frequencies are the same, other methods of investigation have to be used to discover the differences between clear and murmured vowels, and this was outside the scope of my project. However, some differences in formant intensities can be seen in the spectrograms: Formant one (F_1) is often somewhat weakened in murmured vowels (Fig. III.4), and F_4 seems to be comparatively weaker than F_3, i.e. the high part of the spectrum is weakened. It can also be seen that the subformant found in open vowels is somewhat lower than in nasalized vowels.

A more thorough investigation of murmured vowels based on measurements of air-flow, duration, fundamental frequency contour, intensity contour, and intensity measurements of single harmonics besides

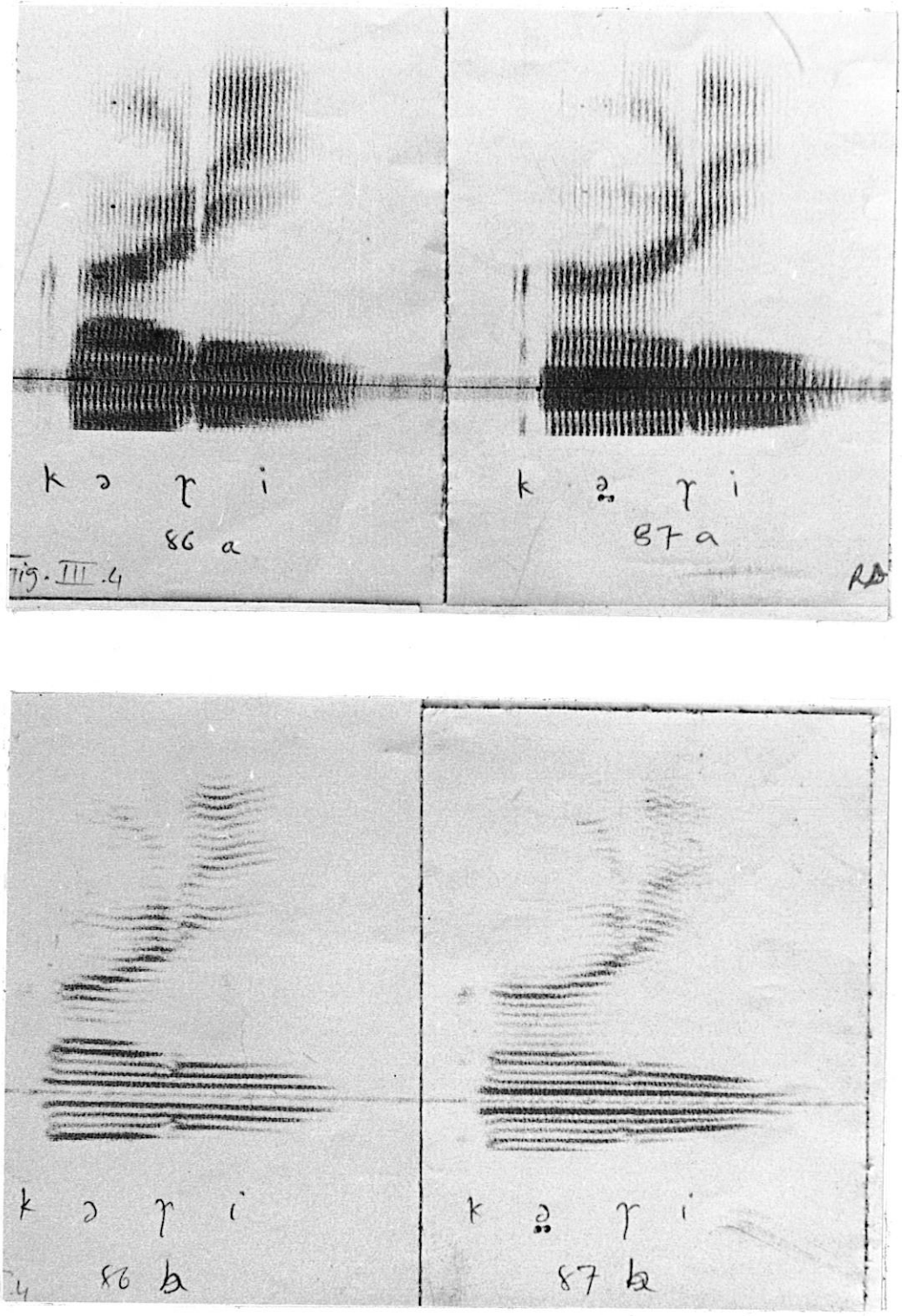


Figure III.4. Spectrog[illegible] of kəri and kə:ri

spectrographic analysis of more informants has been undertaken by Professor Eli Fischer-Jørgensen (1967). The main results of her investigation can be summarized as follows:

(1) Physiologically, murmured vowels are characterized by a strong air flow. The increase of air flow compared to that of clear vowels is 46-110% (depending on the informant). This very stable difference seems to be due to the presence of a small opening in the rear part of the glottis in murmured vowels. In spite of this opening which must cause a less economical utilization of the air flow, murmured vowels have the same physical intensity as clear vowels. It may be assumed that they have a stronger activity of the expiratory muscles. (No measurements of this activity have been taken, but the hypothesis is in agreement with my feeling of stronger stress on murmured vowels.)

(2) Murmured vowels are longer than clear vowels. They start at a lower frequency than clear vowels, and there is often a small tone dip at the start. But they attain the same frequency at the end, i.e. there is a stronger rise.

(3) There is a slower rise in intensity at the start.

(4) The fundamental is relatively strong, compared to the second harmonic and to formants one, two, and four, but not compared to the third harmonic and to formant three. In the wide-band spectrograms this shows up as a darkening around the base line (see Fig. III.4).

(5) There is sometimes a slight weakening of formants 2-4 at the start, accompanied by high frequency noise.

(6) There may be more damping and asymmetry of the speech wave.

Not all these characteristics (except no. 1) need be present in each single case. The longer duration may be due to the historical origin of murmured vowels as a fusion of vowel with h, i.e. it may be a compensatory lengthening.

All the other acoustic features can be explained as consequences to the first feature, viz. the partly open glottis.

Some perceptual tests show that the cues which are most important for perception seem to be the distribution of spectral energy, the low frequency start, and the dip in frequency at the beginning.

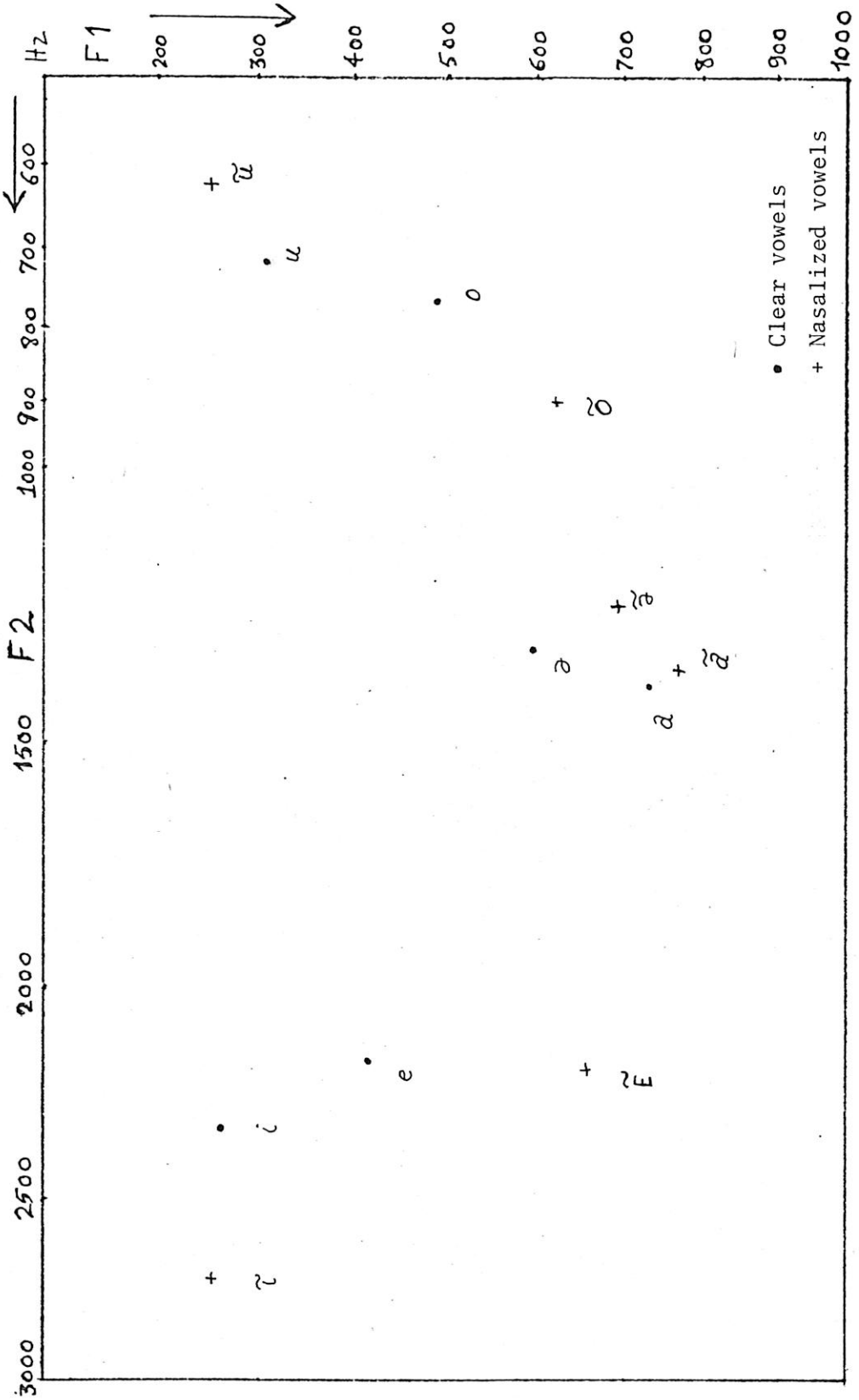


Figure III.5. SK. Clear and nasalized vowels Average (List I A-B)

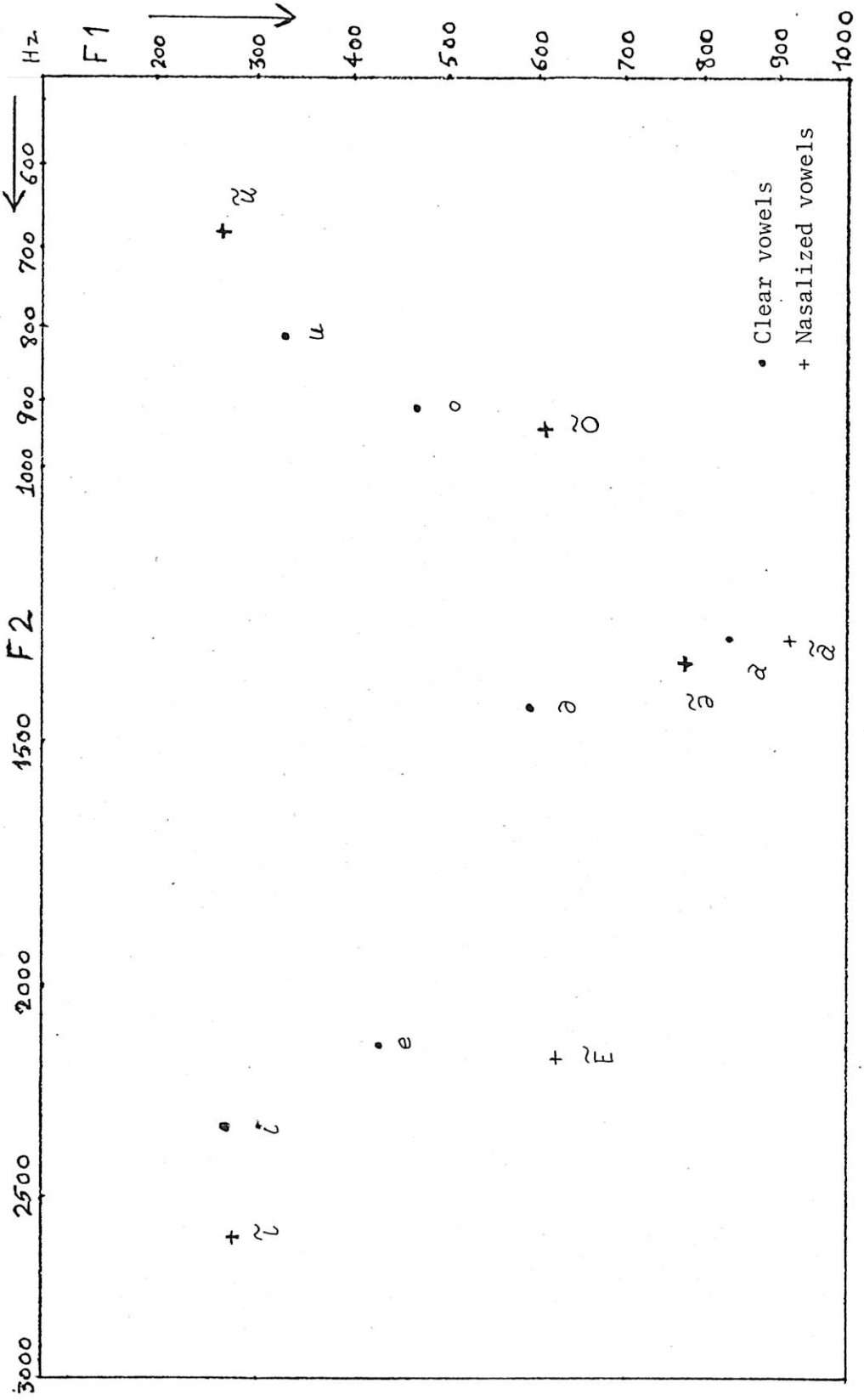


Figure III.6. RD. Clear and nasalized vowels. Average (List I A-B)

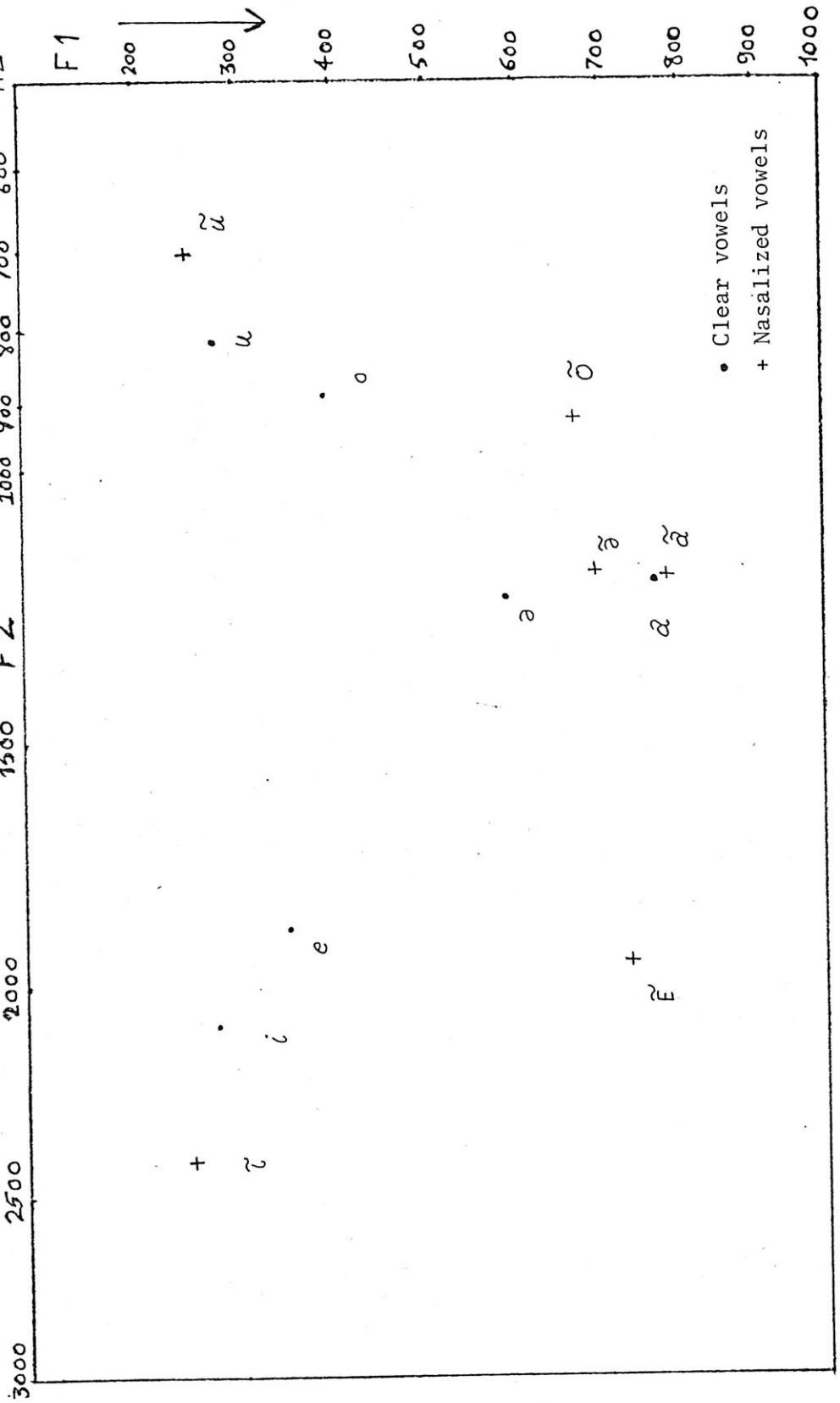


Figure III.7 RT. Clear and nasalized vowels. Average. (List I A-B)

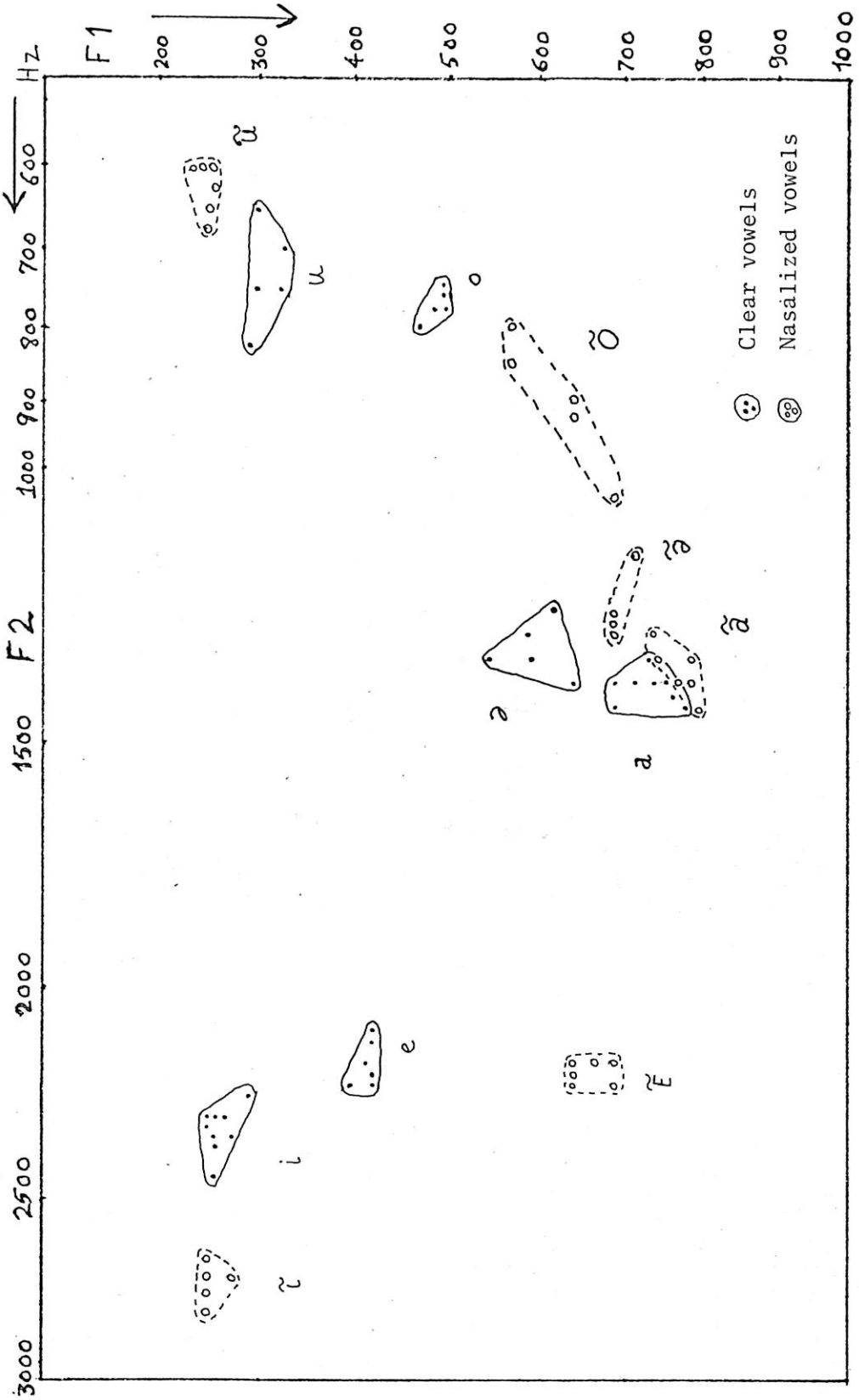


Figure III.8. SK. Clear and nasalized vowels. (List I A-B)

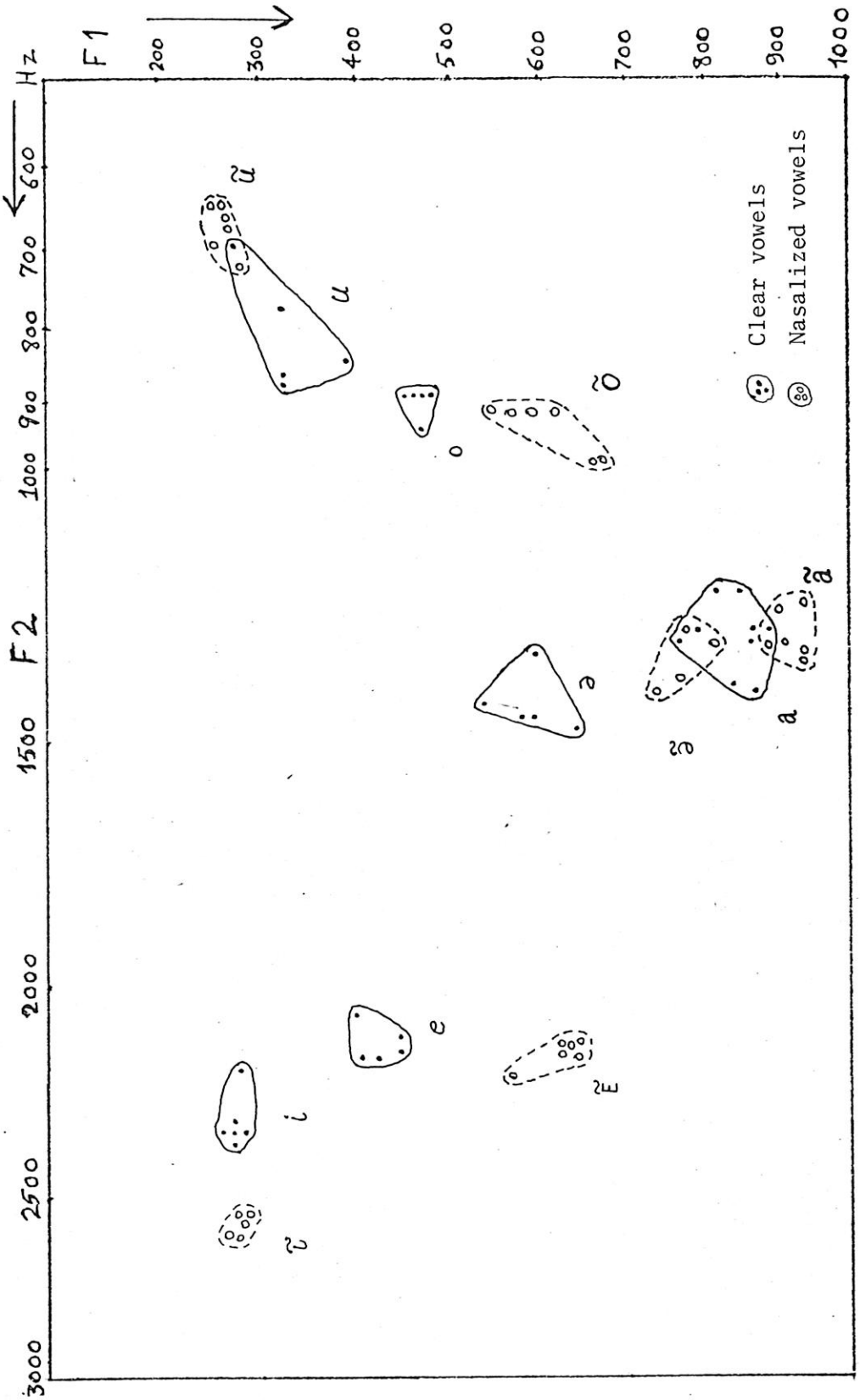


Figure III.9. RD. Clear and nasalized vowels (List I A-B)

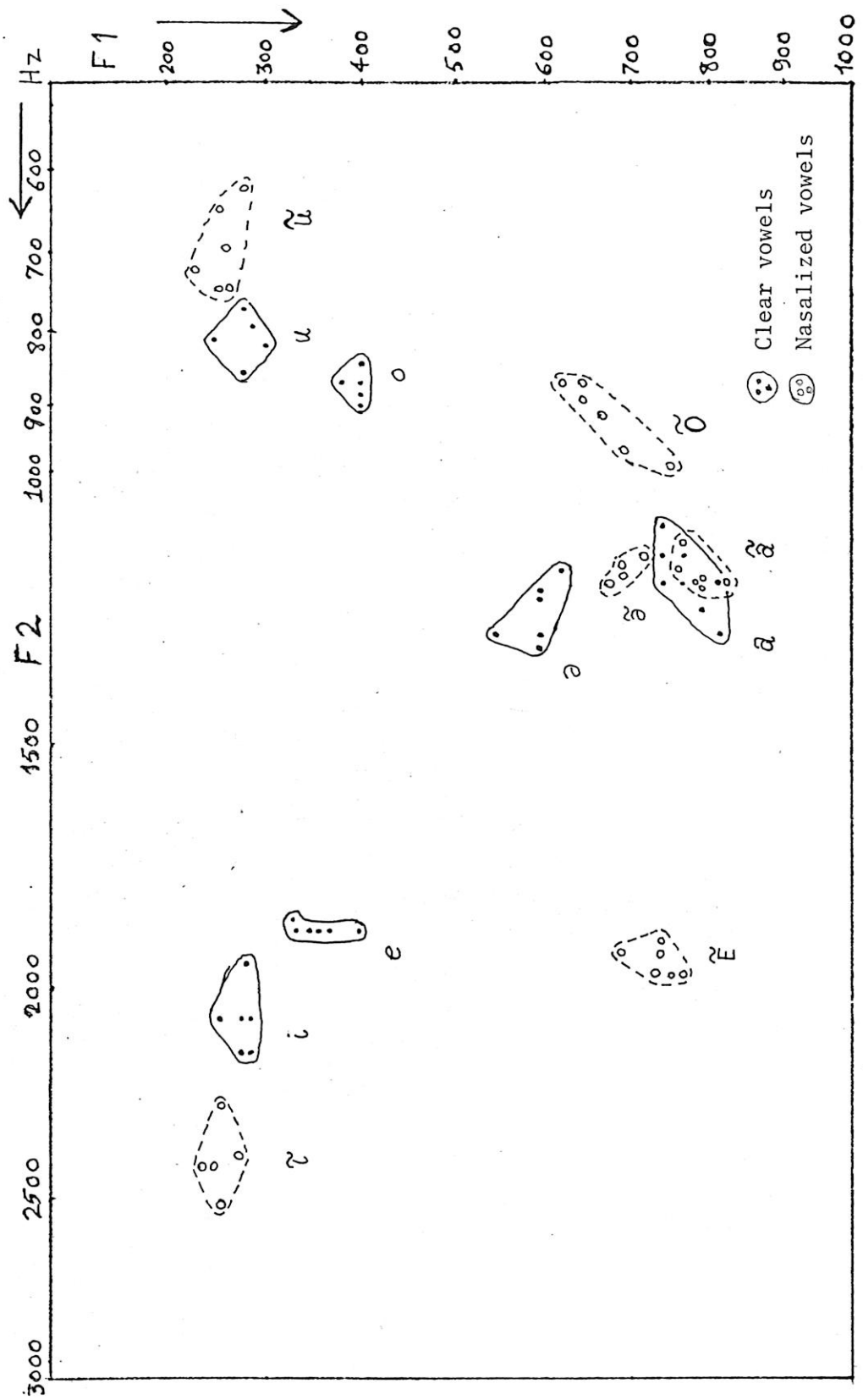


Figure III.10. RT. Clear and nasalized vowels (List I A-B)

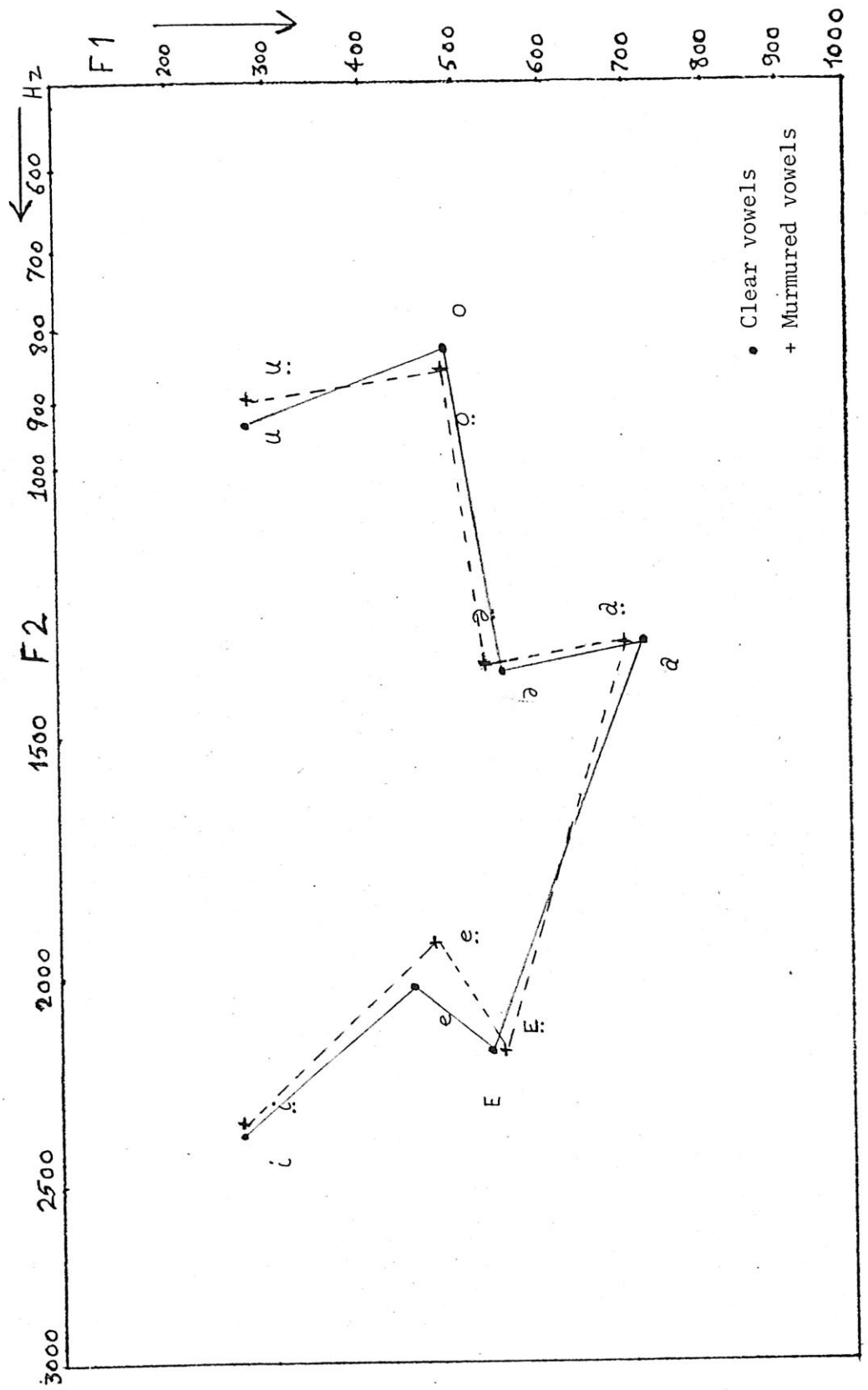


Figure III.11. SK. Clear and murmured vowels. Average. (List IIC)

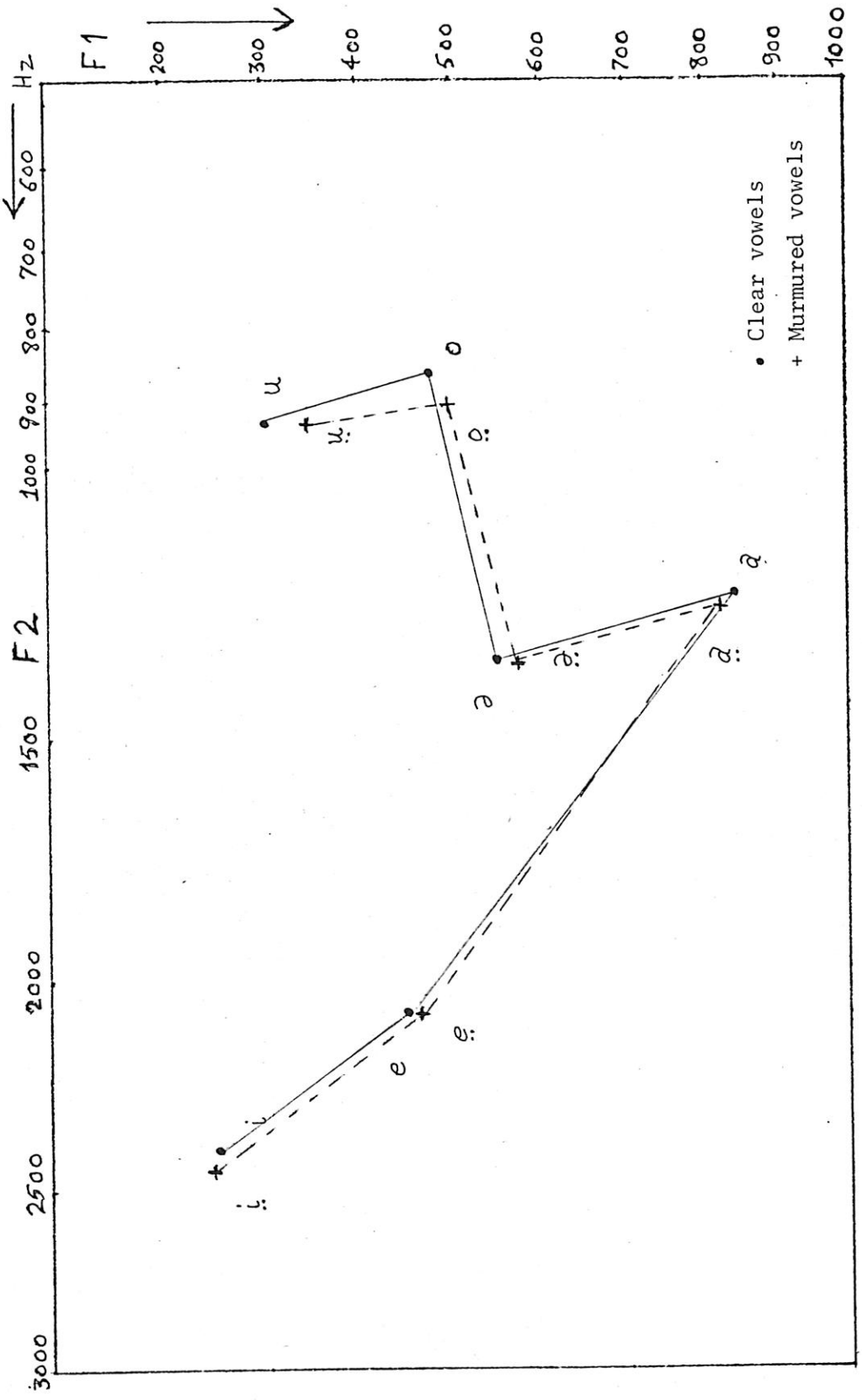


Figure III.12. RD. Clear and murmured vowels. Average. (List IIC)

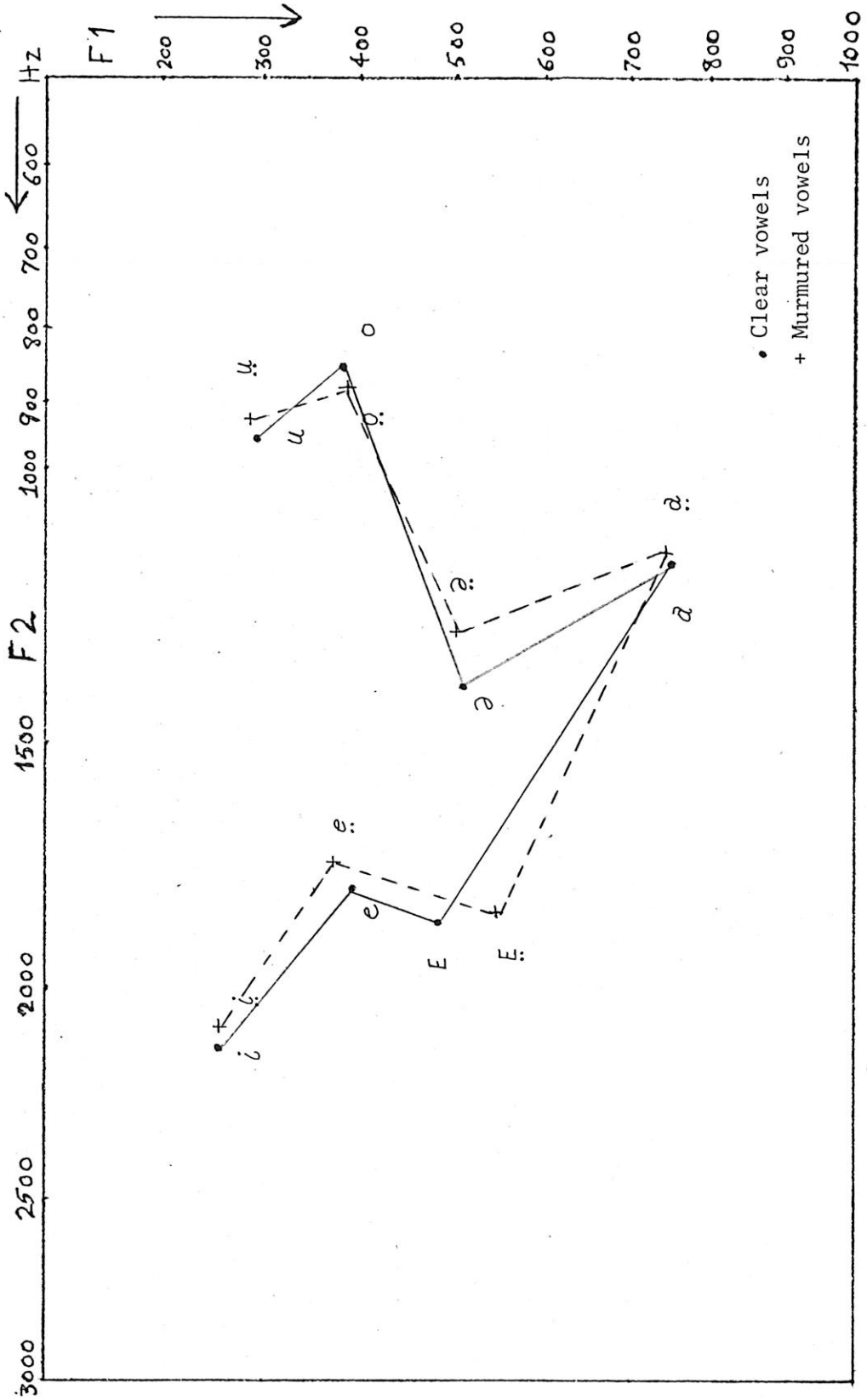


Figure III.13. RT. Clear and murmured vowels. Average. (List IIC)

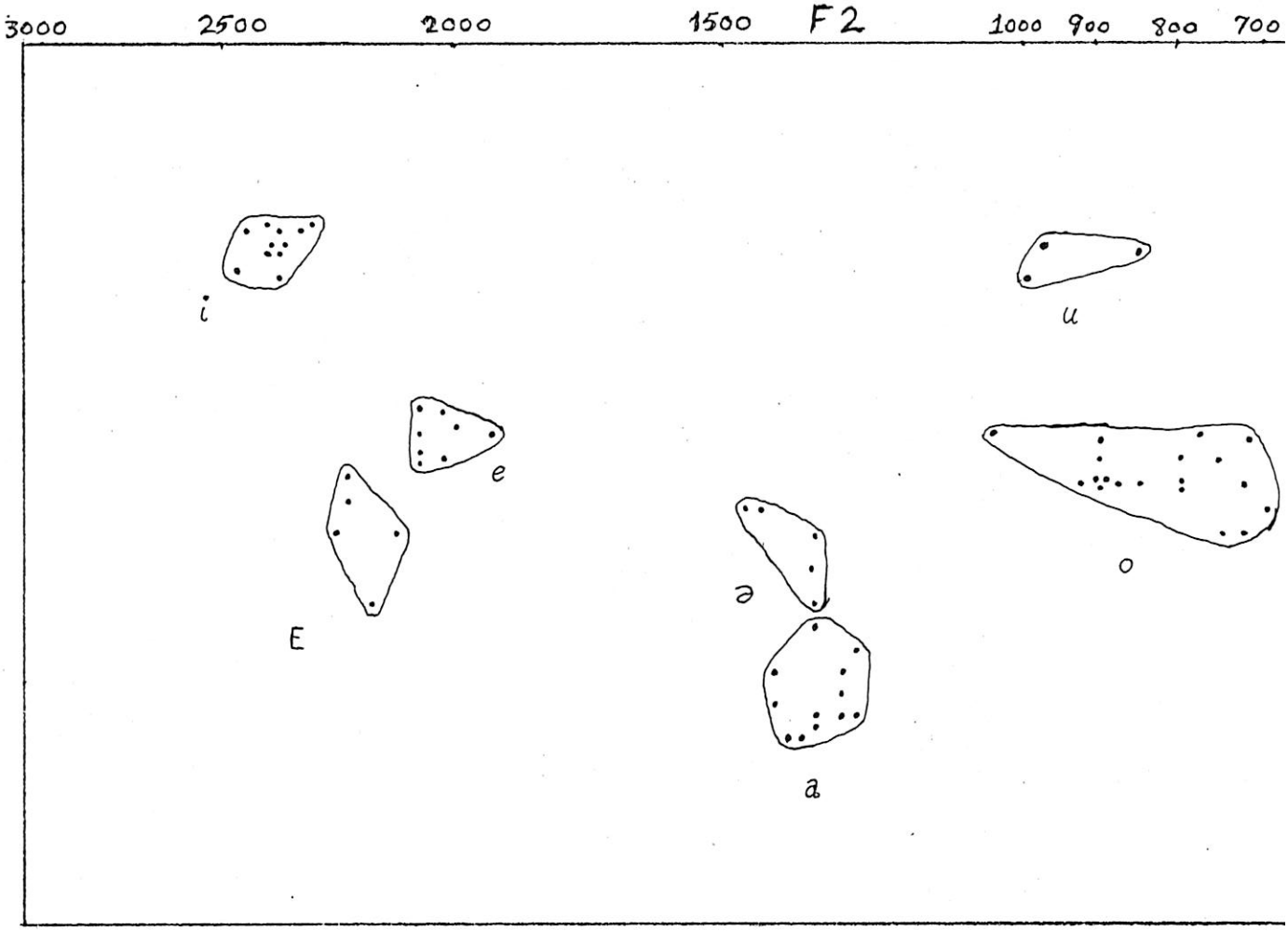


Figure III.14. SK. Clear vowels. (List IIC)

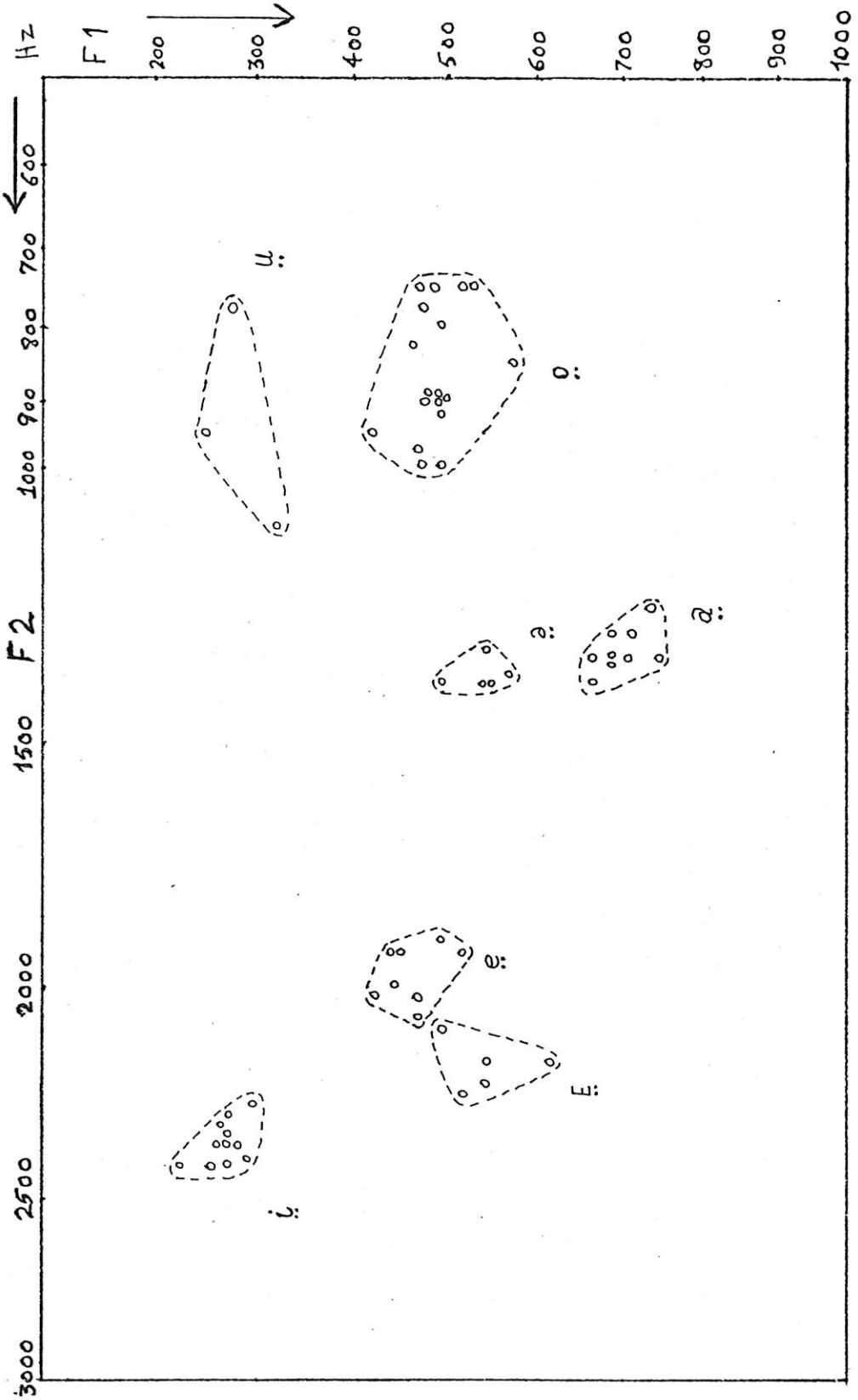


Figure III.15. SK. Murmured vowels. (List IIC)

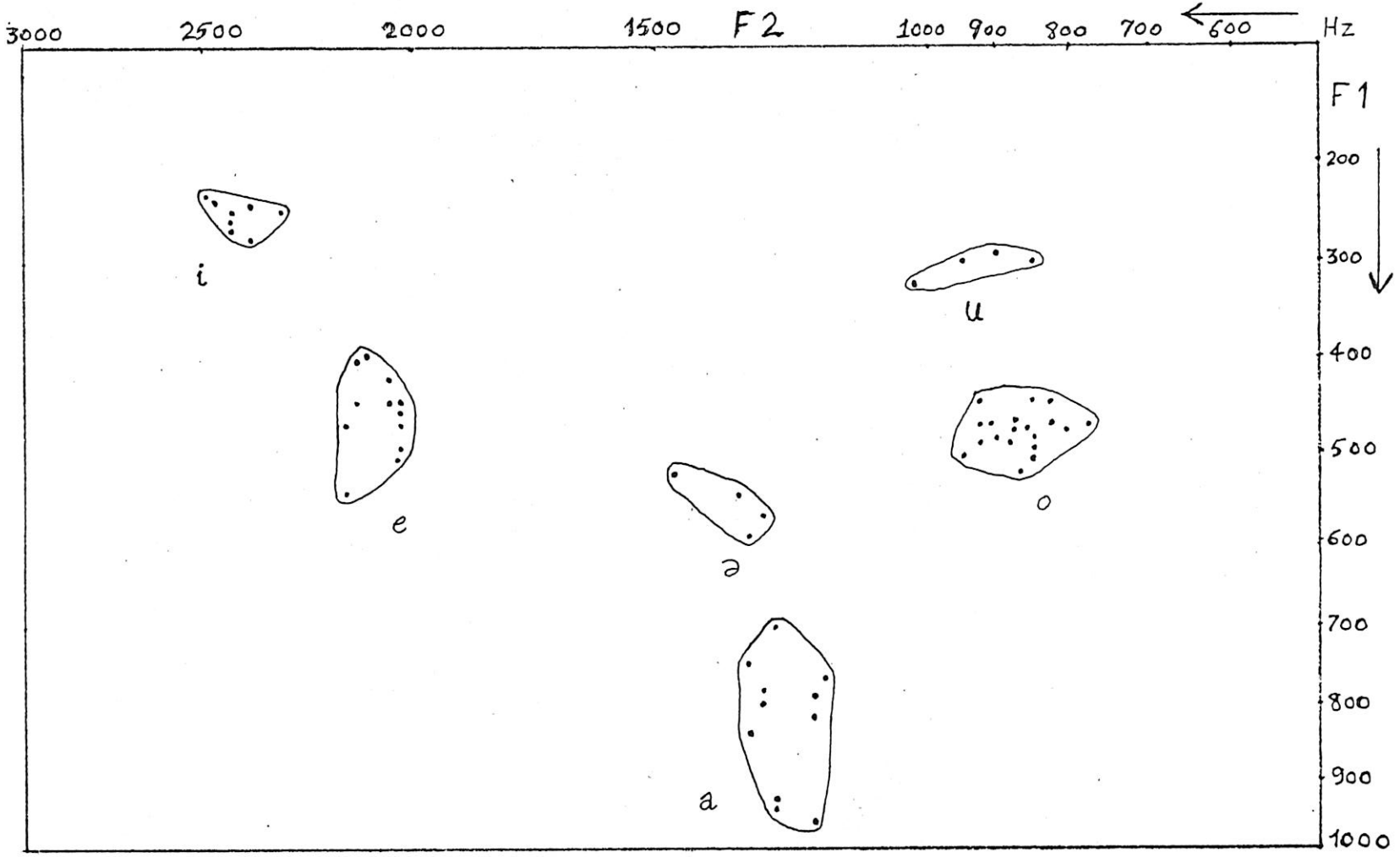


Figure III.16. RD. Clear vowels. (List IIC)

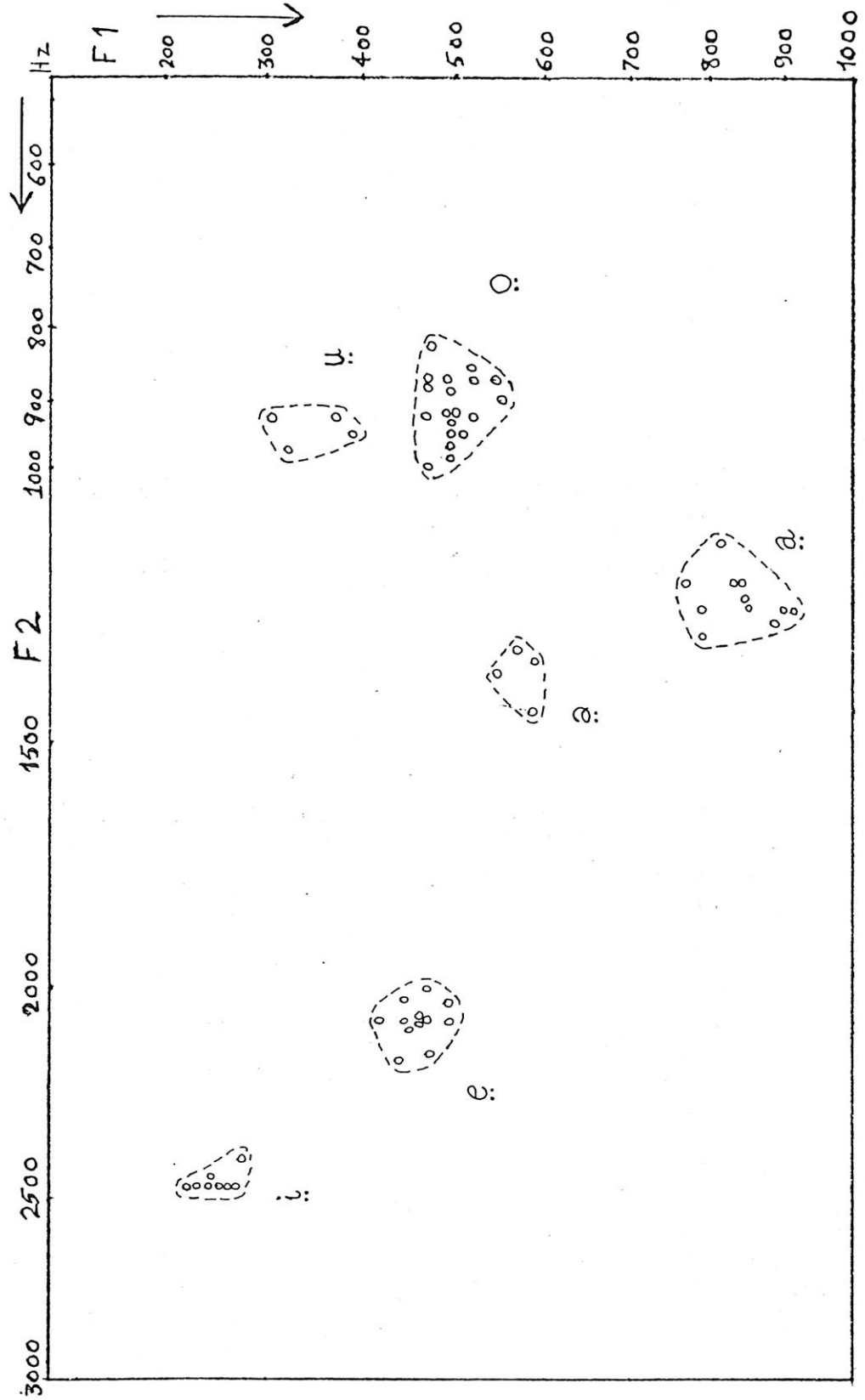


Figure III.17. RD. Murmured vowels. (List IIC)

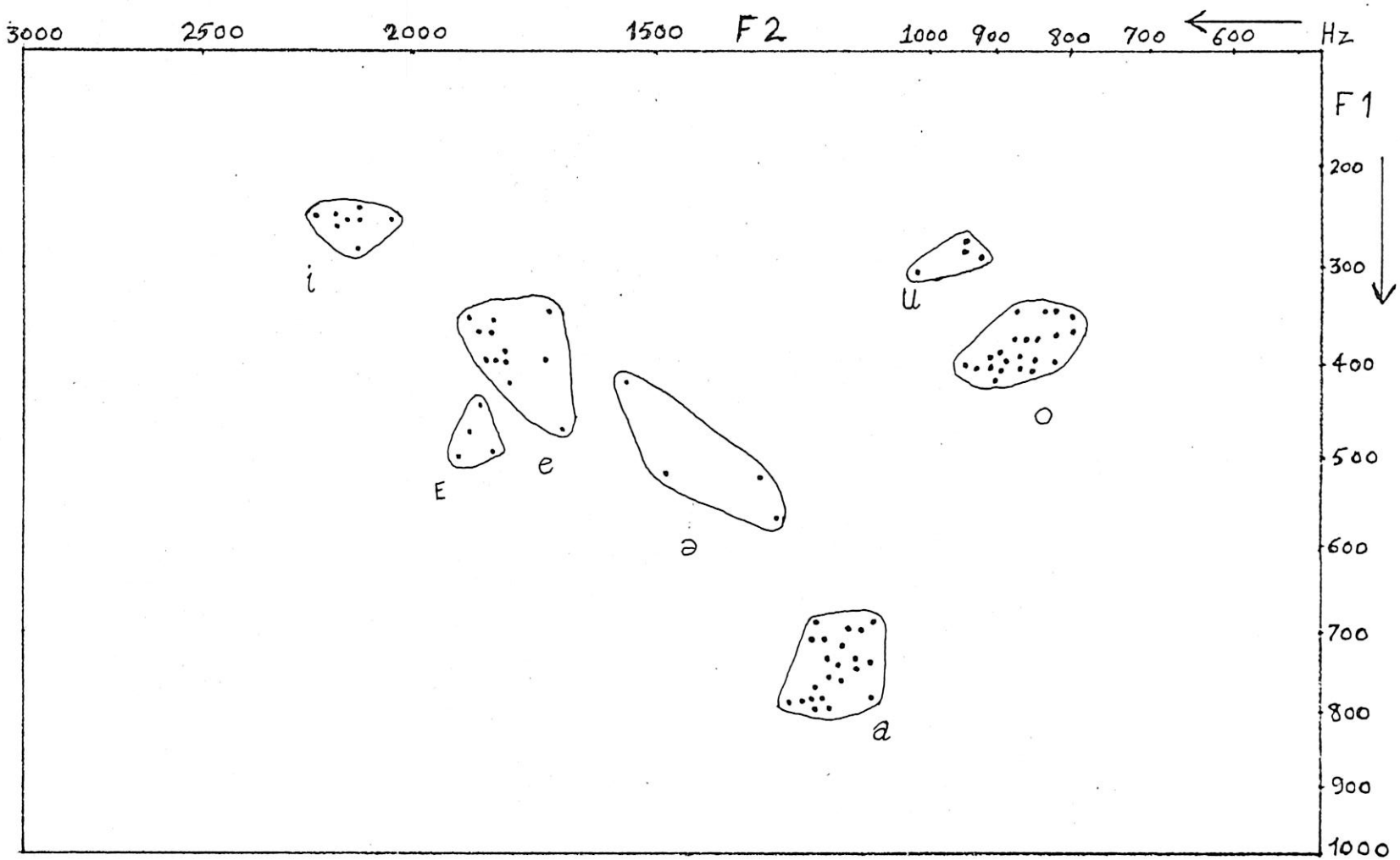


Figure III.18. RT. Clear vowels. (List II C-D)

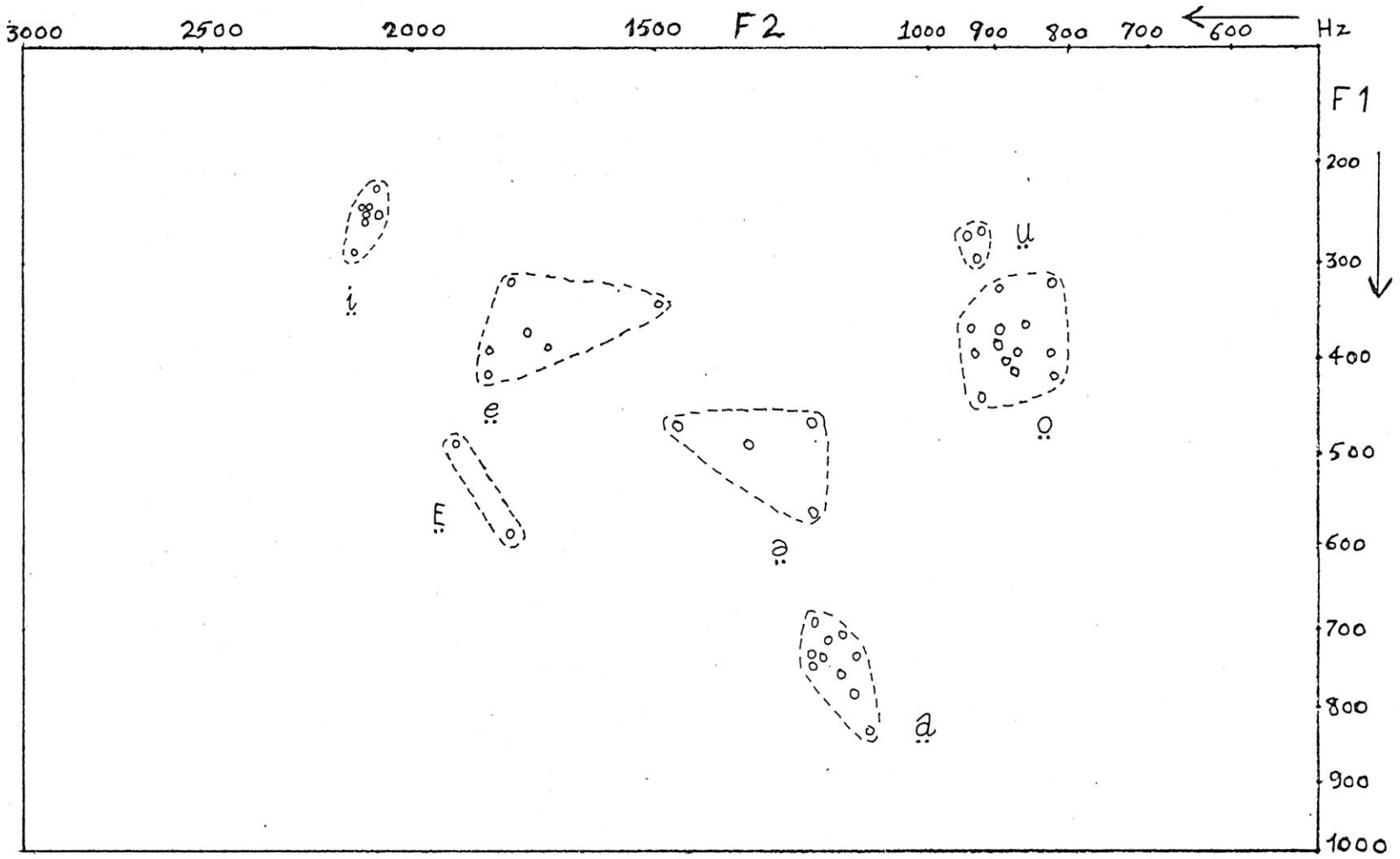


Figure III.19. RT. Murmured vowels. (List II C-D)

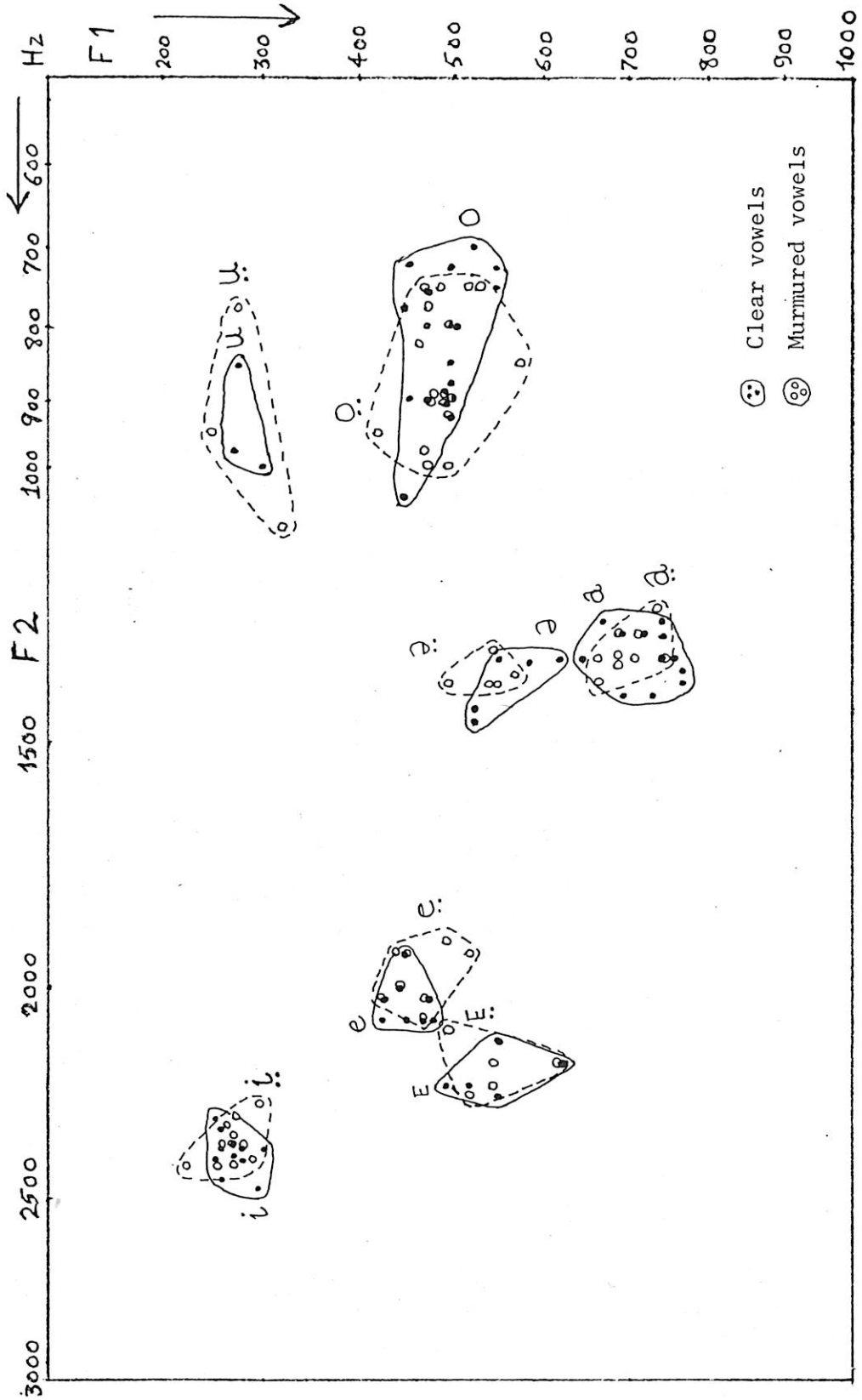


Figure III.20. SK. Clear and murmured vowels. (List IIC)

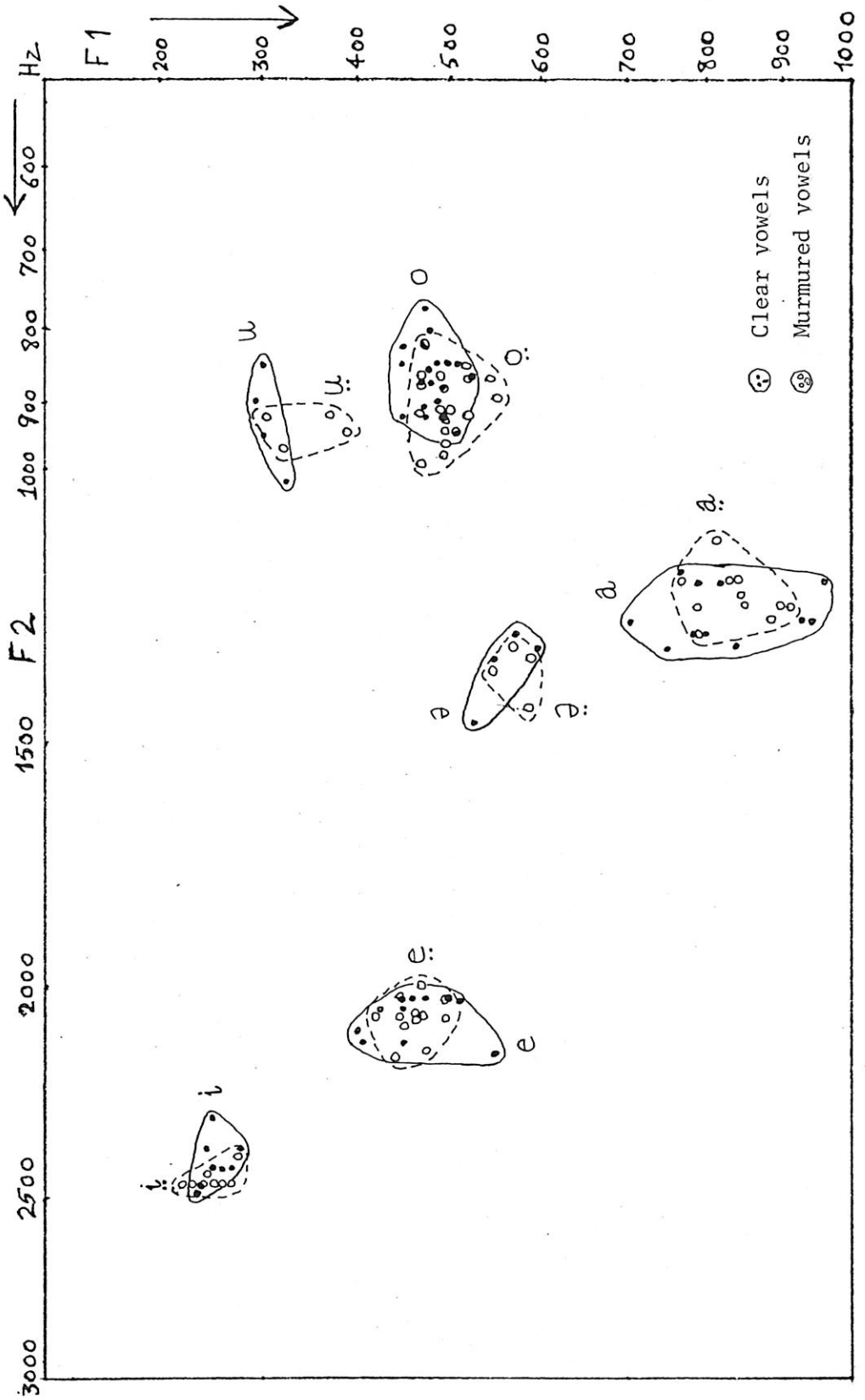


Figure III.21. RD. Clear and murmured vowels. (List IIC)

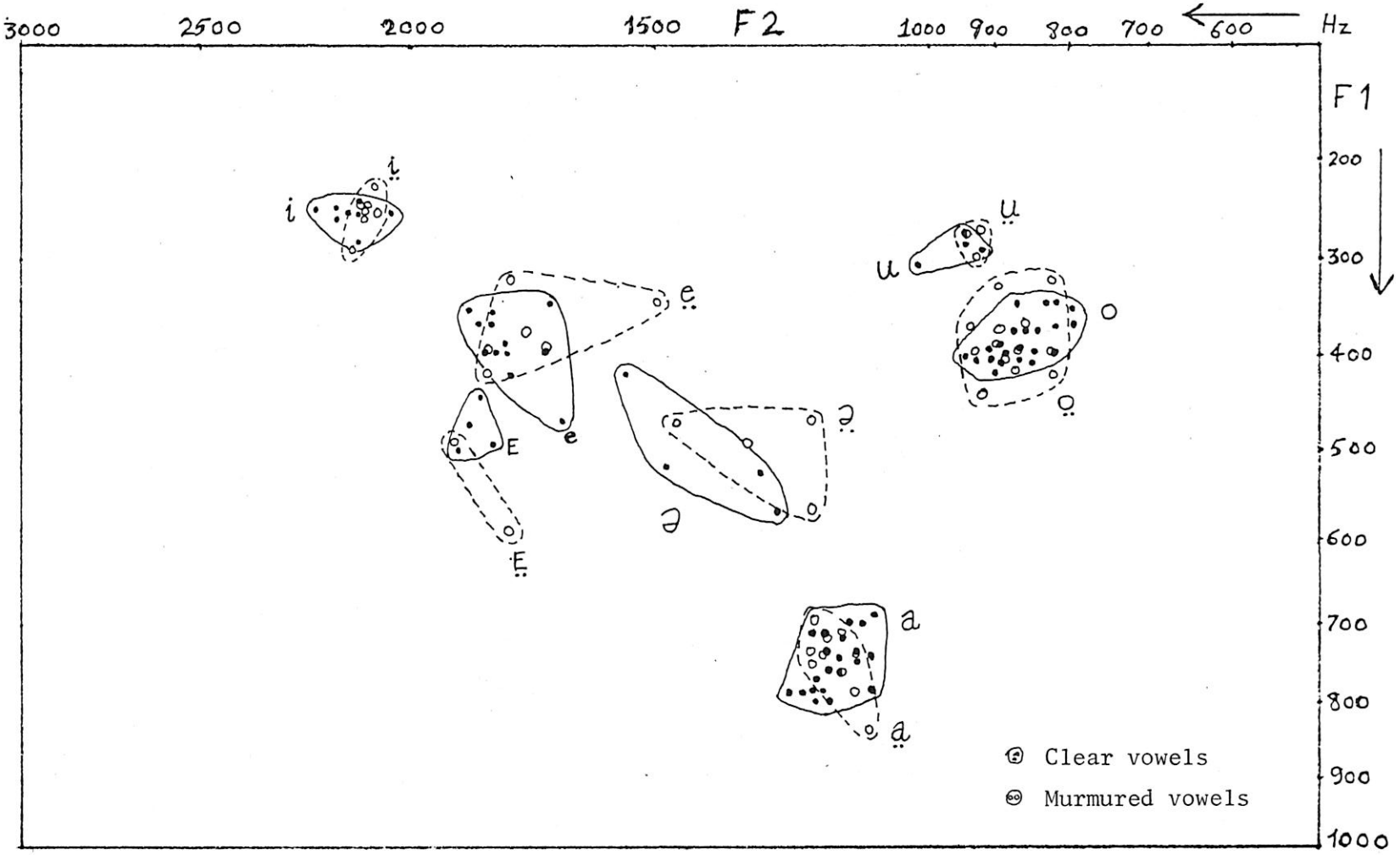


Figure III.22. RT. Clear and murmured vowels. (List II C-D)

CHAPTER IV

PHONETIC ANALYSIS OF DENTAL AND RETROFLEX CONSONANTS

IV.0. Introductory.

In Chapters I-II it was mentioned that Gujarati has a number of retroflex consonants, and it was demonstrated that there is a phonological opposition between retroflex and dental consonants. It is, therefore, of interest to investigate the phonetic differences between these two types of consonants in more detail, particularly since nobody has undertaken such an investigation of Gujarati consonants so far, and instrumental investigations of retroflex consonants in other languages are rather scarce. N. Ramasubramanian and R.B. Thosar (1971) have undertaken a palatographic and spectrographic investigation of retroflex consonants of Tamil; P. Nihalani (1974) has investigated Sindhi stops by means of palatography and X-ray, and K.N. Stevens and S. Blumstein (1975) have undertaken a spectrographic study of retroflex consonants in Hindi. However, the point of articulation of retroflex consonants varies a good deal in different Indic languages, so that no direct conclusions can be drawn for Gujarati from these investigations. According to the traditional description of retroflex consonants they are pronounced with the apex of the tongue curled back to the palatal region; they may, however, also be postalveolar. Firth (1950b) says that the retroflex consonants in Hindi are not pronounced with curled tongue, but he does not give any

It is also well known that American retroflex r may be pronounced in two different ways: either with the tip of the tongue curled back, or with the body of the tongue constricted and bunched up, with an almost identical acoustic effect, viz. a lowering of formant 3. The present writer therefore decided to make a palatographic and spectrographic investigation of the Gujarati retroflex consonants ṭ ḍ ṛ ḷ and ṇ and the corresponding dentals t d r l n. As for the stops the material has been restricted to unaspirated types. The investigation was started in Copenhagen in 1967 and taken up again in 1977.

IV.1. The palatographic investigation.

IV.1.1. Methods of palatography.

By means of palatography it is possible to locate the place on the roof of the mouth which has been touched by the tongue and thus to determine the place of articulation. This also allows for some preliminary and rough conclusions about the size of the oral cavities responsible for the formant structure.

There are two different palatographic methods: indirect palatography and direct palatography. Indirect palatography makes use of an artificial palate sprayed with chalk powder which is removed by the tongue at the places of contact, whereas direct palatography employs the method of painting or spraying the palate or the tongue of the subject. If the

palate is painted, the tongue will remove the paint at the places of contact. If the tongue is painted, it will put marks of paint on the palate at the places where it has touched. Both indirect and direct palatography have been used since the seventies of the past century. Both methods were first used by dentists, and then by phoneticians. After a while, direct palatography went out of use, but it was taken up again at the end of the forties at various places, and is now the most commonly used method. (For the history of palatography, see Moses (1940) and Abercrombie (1957), and for a more detailed discussion of the direct palatography, see Witting (1953), Anthony (1954), Ladefoged (1957), and Abercrombie (1957).)

The indirect method, using an articifial palate, has the advantage that it can be used to investigate one's own articulation, since the artificial palate can be taken out after the pronunciation of each word for the purpose of copying the picture, and it can as easily be replaced again. Direct palatography, on the other hand, requires a light source and a system of mirrors for the purpose of photographing the palate; it therefore also requires a helper. Moreover, it is not very agreeable to have the tongue painted again and again. The first problem has, however, been solved recently by use of the so-called "polaroid dental kit," consisting of a mirror mounted on a polaroid camera, so that the subject can take the pictue himself. The inconvenience of having the tongue or the palate painted can, however, not be avoided.

But the direct method is preferable to the indirect method for various reasons: (1) the use of an artificial palate, however thin it may be, changes the shape of the vocal cavity. It is easy to get accustomed

to by using it, but in order to obtain the same acoustic result, the person may change his articulation slightly. (2) Moreover, it is difficult to take the artificial palate out without touching the roof of the mouth. (3) The artificial palate can only cover the hard palate. If it goes beyond the limit between the hard and the soft palate it will be pushed down when the soft palate is lowered for nasal sounds or for respiration. Painting, on the other hand, can be made as far back as the subject can tolerate.

Various techniques have been used for presenting the results of palatographic investigations. The most common method is, of course, to present photos of the palatograms. But for a more precise description of the areas of contact various scholars have suggested to divide the picture into zones by means of horizontal and vertical lines. Firth (1950b) divided the palatogram into sections by using horizontal and vertical lines based on the dentition of the subject. The horizontal lines ("incisor line", "lateral incisor line", "canine line", etc.) were numbered from one to seven, and the areas of contact could be described by reference to these lines. Witting (1953) also refers to the teeth, but for measurements he uses a glass plate with milimeter divisions. Russell (1928, pp. 335-337) divided the palatogram by dots putting them 1 centimeter apart.

Since photographs and diagrams of the palate generally give a two-dimensional picture, indicating length and width but not depth, Ladefoged (1957) has suggested to accompany each palatogram by a sagittal section of the palate, obtained by sawing along the mid line of a cast of the mouth roof. He further uses the method of drawing contour lines with a fixed

vertical distance. Such methods make it easier to draw conclusions about the size of the cavities on the basis of palatograms.

In more recent times the indirect method of palatography has been taken up again in the form of dynamic palatography. This method uses an artificial palate with a number of embedded electrodes. There may be up to 64 such electrodes. They are connected to a computer via thin wires coming out of the corners of the subject's mouth. When the tongue touches the palate it shortcircuits pairs of electrodes, and each pulse is recorded by means of the computer at short time intervals, showing movements of the tongue. (see, e.g., Palmer (1972), Fuji et al. (1971), and Hardcastle (1968 and 1972).

IV.1.2. The method used.

For the present investigation, the dynamic palatographic method would have been very adequate, particularly for the flapped retroflex sounds. But the present writer did not have access to this instrumentation. The method used was a more traditional, direct method. The tongue of the subject was painted with a mixture of charcoal, chocolate, water, and liquid glue. The subject takes care not to close his mouth before pronouncing the word to be investigated. Immediately after having pronounced the word he moves his head forward, so that an oblique mirror mounted on a frame is inserted into his mouth as far back as possible. The frame also contains a light source and some reflecting mirrors, directing the light into the mouth, and a camera. A picture is taken by a helper. The picture may be slightly distorted if the mirror is not at right angles to the palate.

A normal means of presentation would have been to make paper copies of the photos. Instead, a somewhat different procedure was used: A photo was taken of a cast of the palate; it was then developed in natural size. A number of horizontal and vertical lines were drawn on this photo at a distance of 5 mm. This type of reference lines were preferred to reference lines based on the teeth, because it is the absolute size of the cavity which is of importance for the acoustic output, and also because subjects may have defective dentition, and therefore reference lines based on the dentition are not so easily comparable from one subject to the other. The picture of the palate with the reference lines was then produced in a great number of copies, and the areas of contact were drawn on these copies by inserting the negative film in a projector and projecting the pictures onto the diagram of the palate. This drawing can be done with great precision and it combines the advantage of being cheaper than photographic copies with the advantage of having reference lines on each picture. No attempt was made to add the vertical dimension.

Fig. IV.1 shows this schematic drawing of the palate with the lines numbered from 0 to 10. The center of the alveolar ridge is just slightly above line number 2, the highest point of the palate is reached at line 5 which is considered to be the approximate dividing line between the pre- and post-palatal regions. The boundary between the hard and the soft palate is approximately at line 10. Fig. IV.1 is given here for a general reference to all palatograms given in IV. Note that the left side of the palate is to the right on the paper and vice versa.

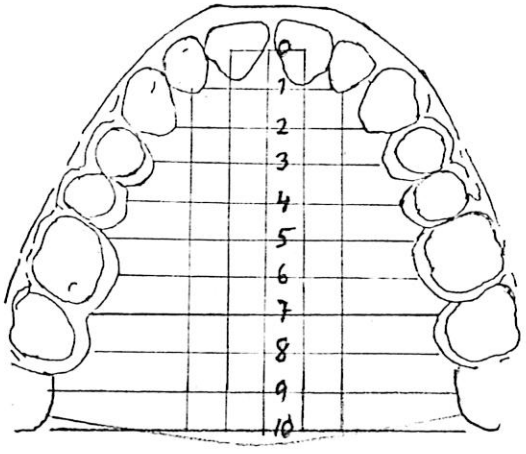


Figure IV.1. Schematic drawing of the palate with numbered lines.

IV.1.3. The material.

Appendix C contains the word lists used for the investigation of consonants. Palatograms were taken from lists I-III, IIa, IIIa, and VIIa. List I was a preliminary list containing dental and retroflex consonants in medial position in the environment a-o or a-i, and in final position. The initial consonant was p. List II is the main list. It includes words with dental and retroflex consonants occurring in initial, medial, and final position. However, as the retroflex consonants ṛ, ḷ and ṇ do not occur initially in Gujarati, the list contains these consonants in medial and final position only. In this list care has been taken to use words in which only the sound under investigation has contact between the tongue and the palate. For this purpose, the vowel a has been chosen both as preceding and following vowel. a is a central, low vowel in Gujarati, and it generally does not have contact with the palate; in any case, the contact is so far back that it does not interfere with dental and retroflex consonants. All consonants, except those to be investigated, are labials.

However, it may also be of interest to see whether the place of articulation is influenced by the surrounding vowels. For this purpose list III (with the vowel i) and list VIIa (containing a few words with u) were used. The vowels u and i have contact between tongue and palate at the sides but not in the middle, and it is therefore possible to see whether there is any difference between consonants in a-, u-, and i-surroundings around the mid line of the palate. List IIa and list IIIa containing velars were added for the purpose of comparing retroflex and velar consonants.

IV.1.4. Subject.

The present author (RD) acted as his own informant (see III.2.1 for bio-data).

IV.1.5. Number of palatograms.

Generally 4 to 5 palatograms have been taken with the vowel a in all positions, i.e. before and after a, and intervocally between two a's. In the environment of the vowels o, i, and u-u, the number is between 2 and 3.

IV.1.6. Results.

Figs. IV.2-55 show tracings of palatograms. The hatched area indicates a typical case, whereas the dotted lines indicate a different example, in principle a rather extreme case and thus giving a rough idea of the degree of variation. In the following, the typical case is referred to as a, the atypical as b.

IV.1.61 The dental stops.

Palatograms of the voiceless and voiced dental stops together with the retroflex stops are given in Figs. 2-21. Figs. 2-13 show stops in connection with the vowel a. The contact area for the tongue is the dental region and the foremost part of the alveolar region. The front teeth are almost covered. The contact area generally goes back from line number zero to line number 2 and, in a few cases, to line number 3, which indicates the end of the alveolar region.

The area covered by the tongue in the articulation of d does not differ significantly from the area covered by t. On the average, however, d covers a slightly narrower area than t, but the difference is very small. Sometimes, there is no difference at all. Compare, for instance, the palatograms of ɒat and ɒad (Fig. IV.6a, IV.12b). Thus the fortis t does not always cover more area than the lenis d.)

As the contact area is predominantly dental, t and d may be described in articulatory terms as apical dental stops.

The palatograms of t and d in the environment of the front and back vowels i and u show that the environment does not have any influence on the articulation of dental consonants (See Figs. IV.14-21).

IV.1.62. The retroflex stops.

The palatograms of the retroflex consonants are presented adjacent to the palatograms of the dental stops, so that they can be easily compared. As mentioned in IV.0, the retroflex stops are traditionally defined as stops articulated with the apex of the tongue curled back and touching the hard palate. As both the upper and lower surface of the tongue had been painted and could have put marks on the palate, it cannot be decided directly on the basis of the palatograms whether the tongue was curled back or not, but the fact that sometimes the tongue has touched farther back in the middle than at the sides seems to indicate that it was curled back, and I have a very clear feeling that I do curl my tongue back; it can also be observed in a mirror.

The tongue contact is with the hard palate, generally between lines 3 to 6, or 3 to 6.5. Sometimes the contact goes as far back as the lines

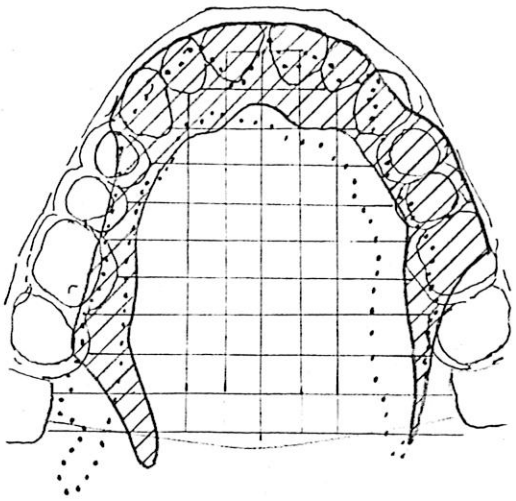


Figure IV.2ab. tap

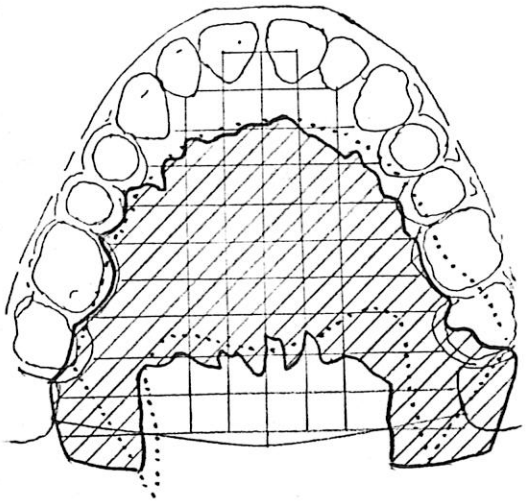


Figure IV.3ab. ṭapu

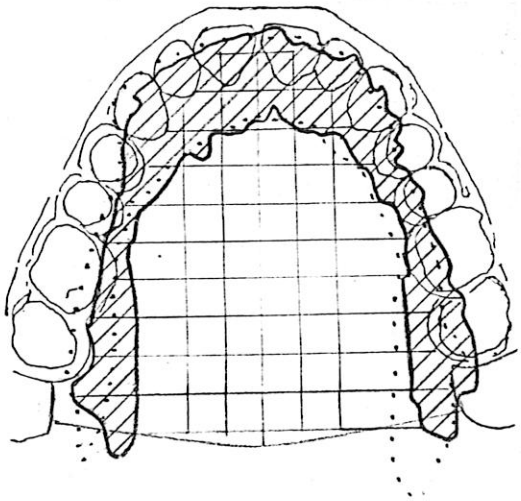


Figure IV.4ab. mata

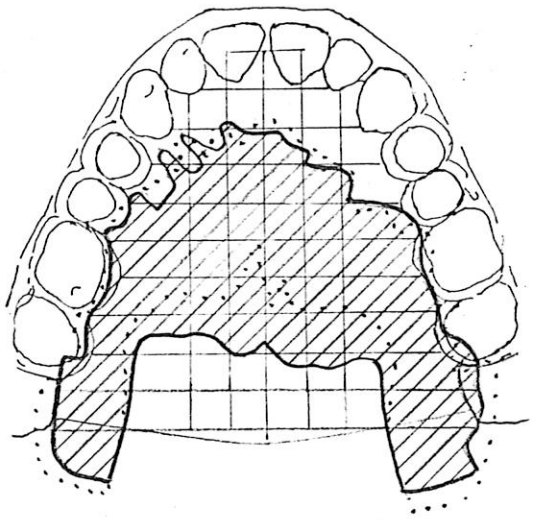


Figure IV.5ab. paṭa

Figures IV.2ab-5ab. Palatograms of tap, ṭapu, mata, and paṭa.

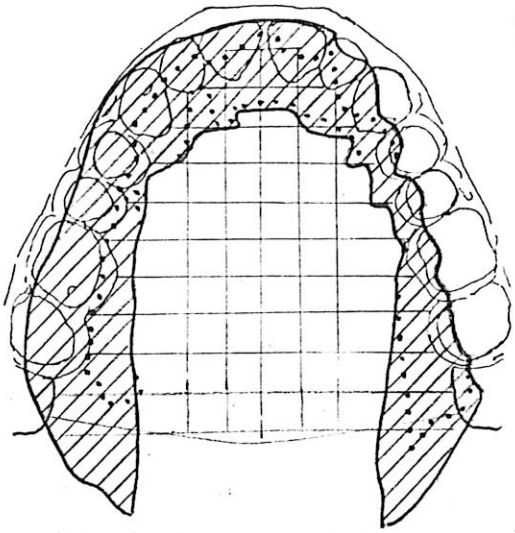


Figure IV.6ab. ɒat

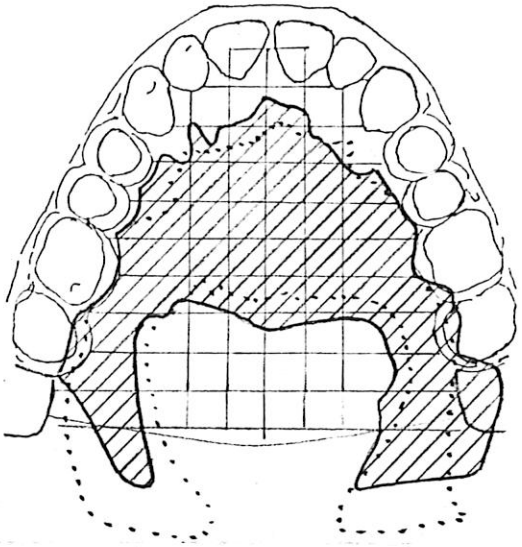


Figure IV.7ab. a̤t

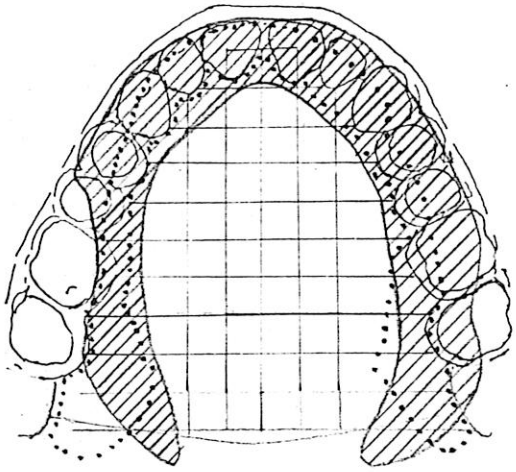


Figure IV.8ab. dab

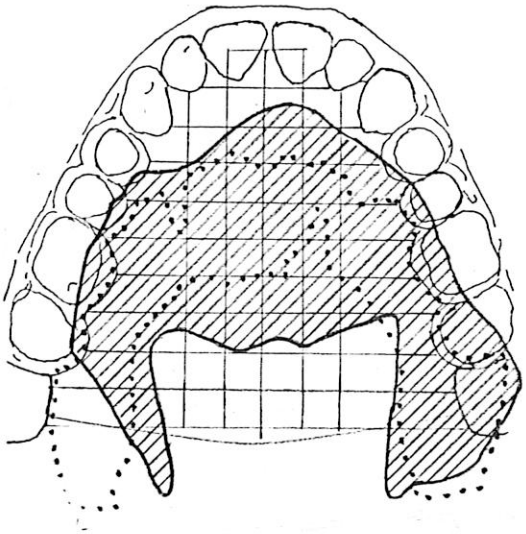


Figure IV.9ab. d̤aba

Figures IV.6ab-9ab. Palatograms of ɒat, a̤t, dab, and d̤aba.

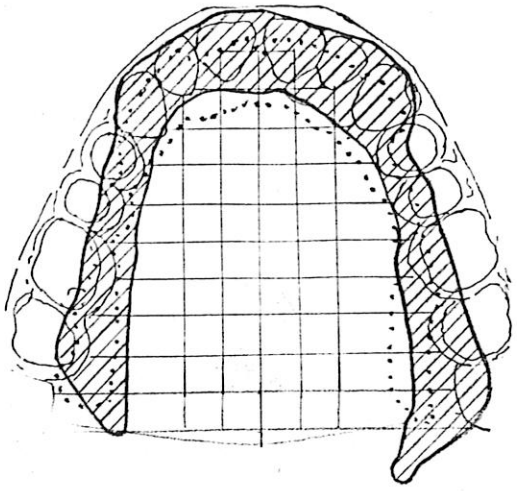


Figure IV.10ab. mada

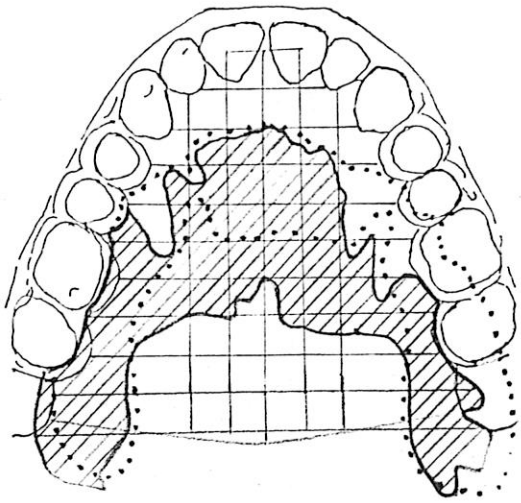


Figure IV.11ab. paḍa

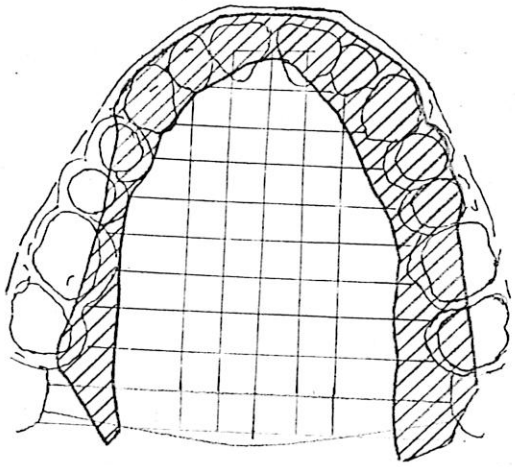


Figure IV.12a. ɒad

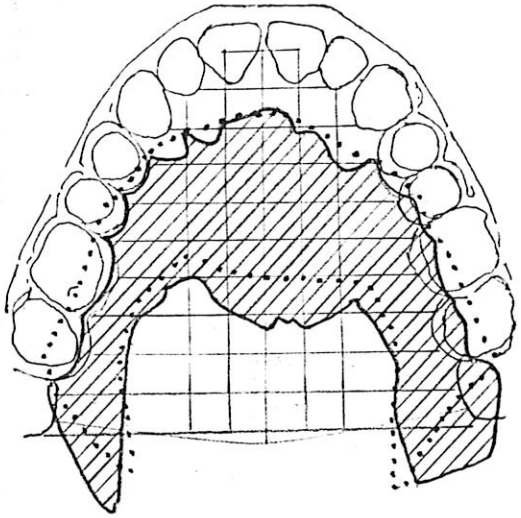


Figure IV.13ab. aḍ

Figures IV.10ab-13ab. Palatograms of mada, paḍa, ɒad, and aḍ.

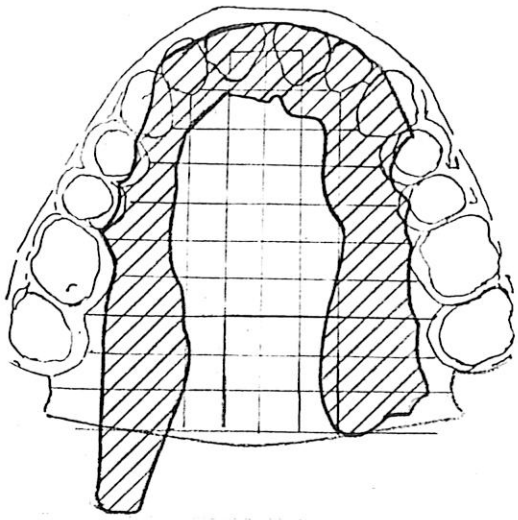


Figure IV.14. iti

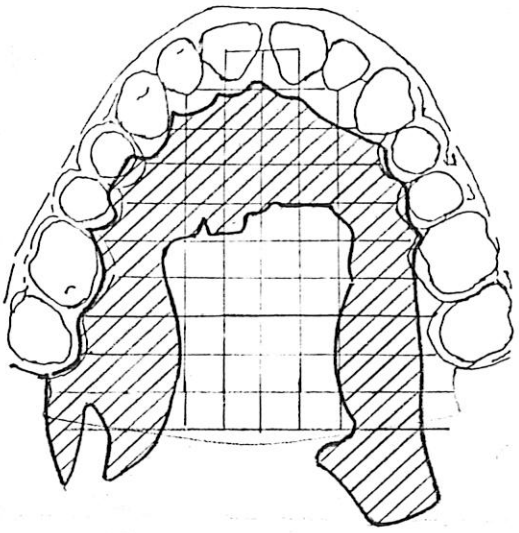


Figure IV.15. piṭi

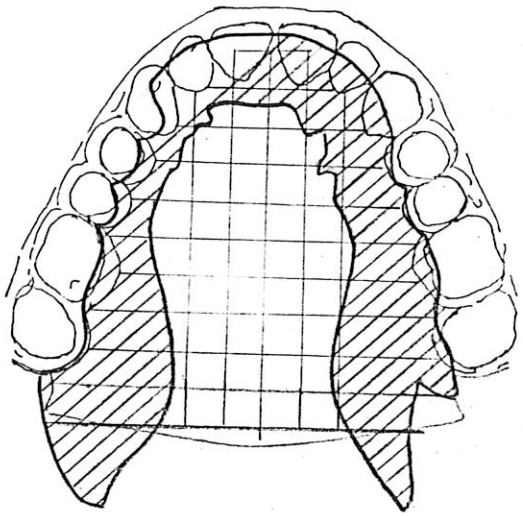


Figure IV.16. sidi

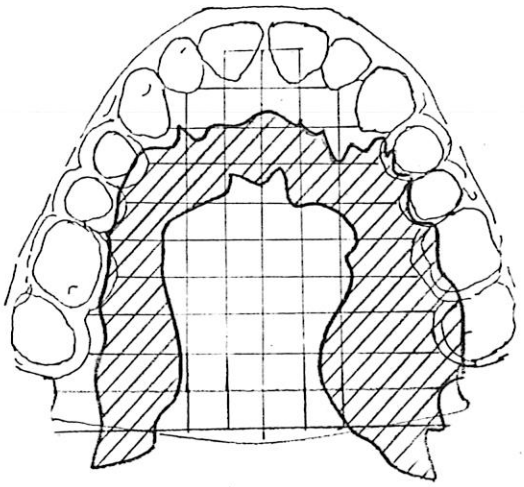


Figure IV.17. iḍər

Figures IV.14-17. Palatograms of iti, piṭi, sidi, and iḍər.

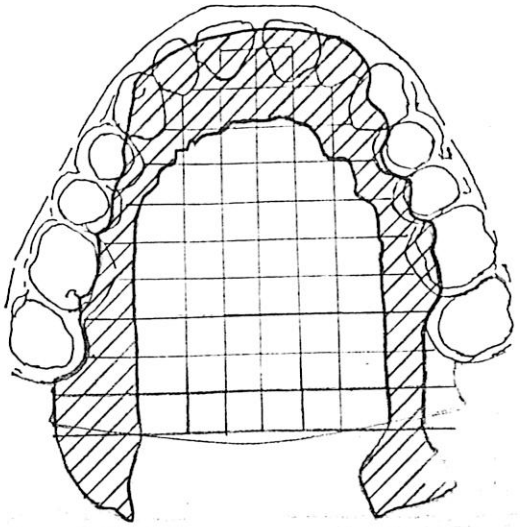


Figure IV.18. hututu

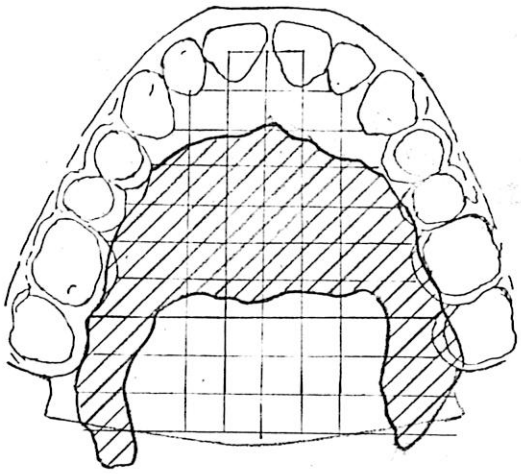


Figure IV.19. moṭũ

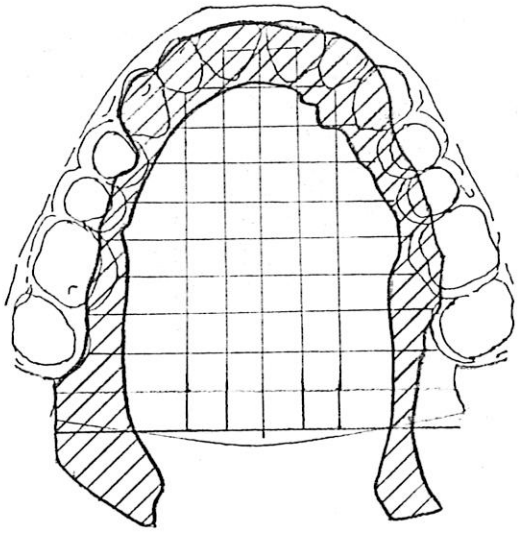


Figure IV.20. bhodu

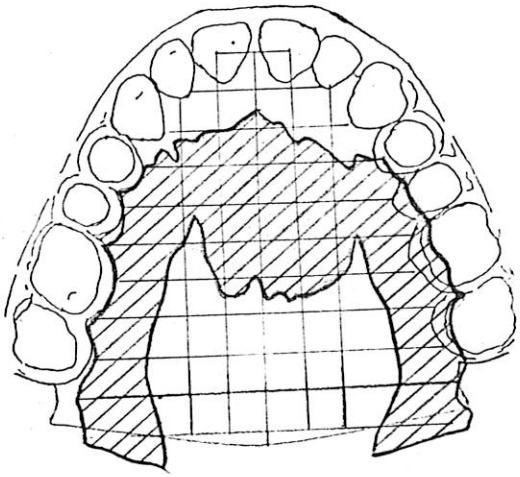


Figure IV.21. uḍũ

Figures IV.18-21. Palatograms of hututu, moṭũ, bhodu, and uḍũ.

7 or 8 (see Fig. IV. 3a, 5a, 9a).

The tongue seems to have contact with a larger area of the palate in the articulation of intervocalic t̤ than in d̤. See, for instance, pata̤ (Fig. IV.5a), and pada̤ (Fig. IV.11a). In the initial position, however, the difference is very small or non-existent.

As we have seen in the previous section, the vocalic environment does not influence the articulation of dental stops. The retroflex stops, on the other hand, seem to be more or less influenced. t̤ and d̤ are slightly more fronted with the front vowel i than with the central vowel a or the back vowel u. Compare the palatograms of pitia̤ (Fig. IV.15) with pata̤ (Fig. IV.5) and motṳ̃ (Fig. IV.19), and similarly idər̤ (Fig. IV.17) with pada̤ (Fig. IV.11) and udṳ̃ (Fig. IV.21), but retroflex and dental consonants are still clearly distinguished (see Figs. IV.14-21).

The articulatory difference between the dental and retroflex stops is clear. Their position of articulation is quite different. Similarly, the manner of their articulation is also different. Moreover, the retroflex stops cover more area of the palate than the dental stops.

IV.1.63. Consonant r.

The articulatory contact for r with the vowels a and i is generally in the alveolar region. The apex of the tongue, however, covers a very narrow area of the alveolar ridge, approximately 5 millimeters (see Figs. IV.22a, IV.24a, IV.24b, IV.27a.). The tongue contact is generally in the area of line number 2.

Some palatograms also show contact with the dental region. For instance, the word rab (Fig. IV.26a) shows marks of the tongue on the front

teeth. Fig. IV.27b of the word paro shows a purely dental r.

There are also other variations of r. Sometimes no closure is seen in the palatograms (see Fig. IV. 22b, IV.26b, and IV.28 for mara, rab, and əmiri, respectively). The dental r and the frictionless r, however, should be considered only to be free alternants of the most frequent alveolar r.

IV.1.64. The retroflex flapped ṛ.

The palatograms of ṛ with the vowels a and i have been placed on the same page as those of r for comparison (see Figs. IV.22-29). As has been said earlier, ṛ, ḷ, and ṇ occur in the medial and final positions only.

The place of articulation for ṛ is the hard palate. The tongue seems to have been curled back obliquely at the left side of the hard palate. The contact area is generally found between the lines 2 to 5, and sometimes between the lines 2 to 6.

The palatogram of the word biri (Fig. IV.29) is different from the other palatograms in two ways: it does not show the oblique contact of the tongue, and there is no complete closure, but a lateral opening at the right side. Such cases are rare.

It should be noted that ṛ in biri, although having a lateral opening, is quite different from the retroflex ḷ in the context of a (cf., for instance, pal in Fig. IV.35a.) and i (cf. pili in Fig. IV.37).

The palatograms taken by me do not show any effect of the front vowel i or r or ṛ (except for the fact that the contact at the left side seems to be slightly more advanced in əmiri). r and ṛ are quite distinct

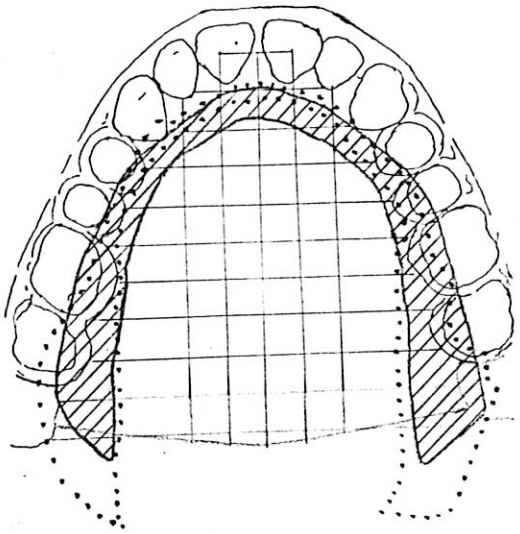


Figure IV.22ab. mara

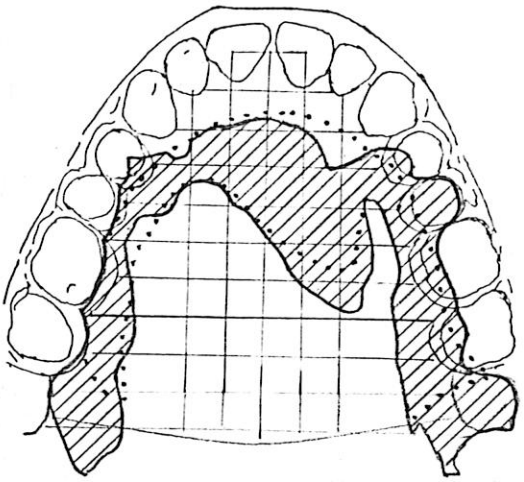


Figure IV.23ab. phara

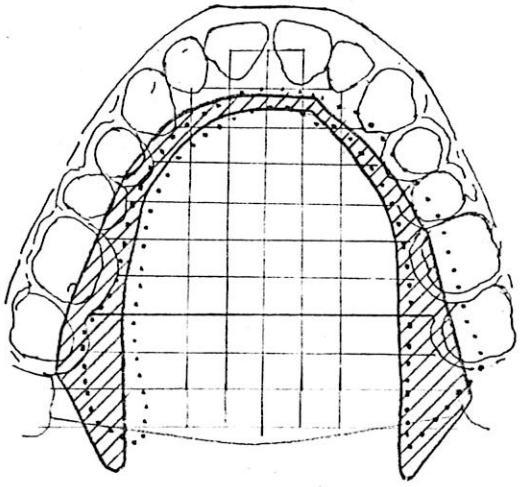


Figure IV.24ab. par

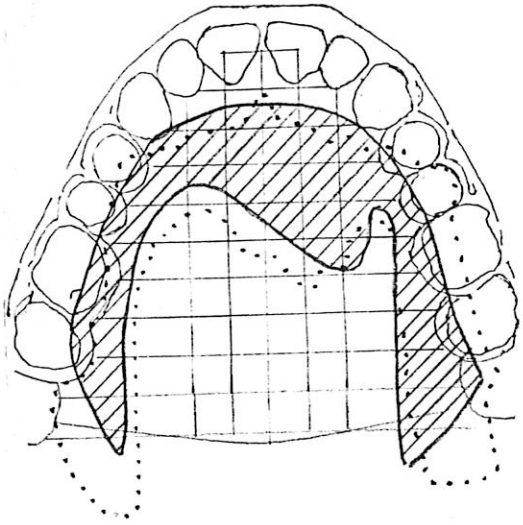


Figure IV.25ab. phar

Figure IV.22ab-25ab. Palatograms of mara, phara, par, and phar.

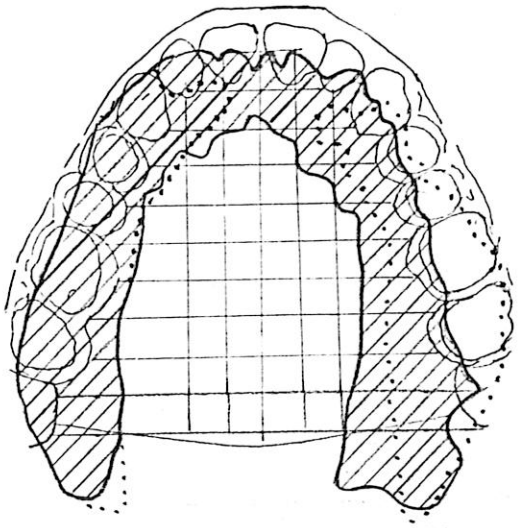


Figure IV.26ab. rab

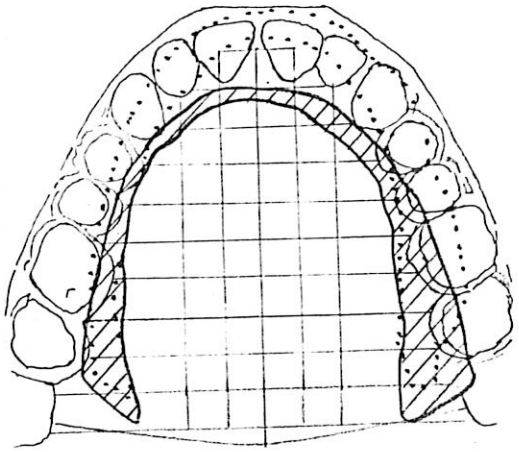


Figure IV.27ab. paro

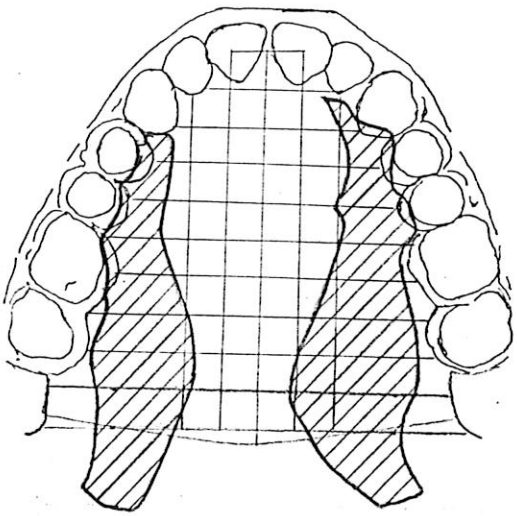


Figure IV.28. əmiri

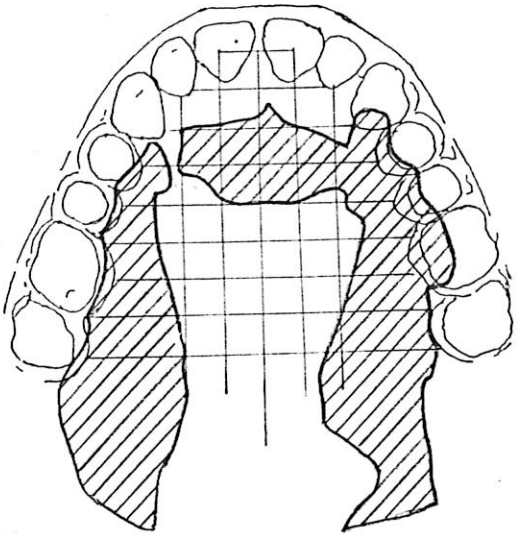


Figure IV.29. biṛi

Figure IV.26ab-29ab. Palatograms of rab, paro, əmiri, and biṛi.

from each other in the palatograms.

IV.1.65. The dental l.

The closure for l is, in most cases, in the denti-alveolar region. The apex of the tongue touches the alveolar ridge and part of the front teeth (see labh and pal in Fig. IV.30, and Fig. IV.34b). Sometimes, the contact is only with the alveolar ridge, e.g. pala (Fig. IV.31b). Also, the front teeth are covered at times: see pala (Fig. IV.31a).

Generally no lateral opening is seen, except in a few cases. See, for instance, pala (Fig. IV.31b). Perhaps the opening for others is in the region of the velum. In case of pala, the opening is somewhat to the left behind the front teeth.

The area of the palate covered by the tongue is generally between lines zero to line 1, but sometimes very narrow area is covered below line number 1 (see pala, Fig. IV.31a).

l seems to be more fronted in the environment of the vowel i; see pili (Fig. IV.36). l differs from the dental stops mainly because of its laterality, and also because of its being articulated at a slightly more retracted place in the dental-alveolar region. The stops generally cover the front teeth. l is also different from r, which is still more retracted than l. Also in other languages r is generally alveolar. It seems to be difficult to produce a purely dental trill or flap.

IV.1.66. The retroflex flapped $\underline{\dot{l}}$.

Retroflex $\underline{\dot{l}}$ has a very characteristic articulation, at least in my

speech. As the palatograms indicate, the articulation is retroflex. The tongue contact is with the hard palate. the intervocalic ḷ has generally opening at both sides (see Fig. IV.3a, bala, Fig. IV.33a, palo). Mostly the major opening is to the left side. Like ṛ, ḷ also shows a somewhat oblique contact going to the left. In final position, ḷ is generally unilateral (see Fig. IV.35a), except in one sample of the word aḷ (Fig. IV.35b) which shows a bilateral opening. The palatogram of ḷ in the word aḷ is, however, quite different from the palatograms of ḷ in other words.

The contact area for ḷ is between lines 2 and 7-8, and it sometimes goes beyond line 8 (see Fig. IV.32a, bala). The final ḷ generally covers a smaller area, that is, between lines 2 and 5.

ḷ seems to be quite different in the palatogram of the word pili (Fig. IV.37). It shows only a slight contact with the pre-palatal region. (The contacts at the sides are due to the vowel.) The opening is at the right side. It is also rather fronted. My data is, however, not exhaustive.

Ramasubramaniam et al. (1971) describe the Tamil ṭ, ḍ, ṇ, and ḷ as medio-palatal retroflex consonants. The palatograms of Gujarati ṭ and ḍ look very similar to ṭ and ḍ of Tamil. The contact for ṭ and ḍ in Gujarati goes, however, many times beyond the mid-palatal region. Gujarati ḷ and ṇ are different from the Tamil ḷ and ṇ by being flapped. Also their contact area mostly goes beyond the mid-palatal region (see section IV.1.68 for the discussion on Gujarati ṇ).

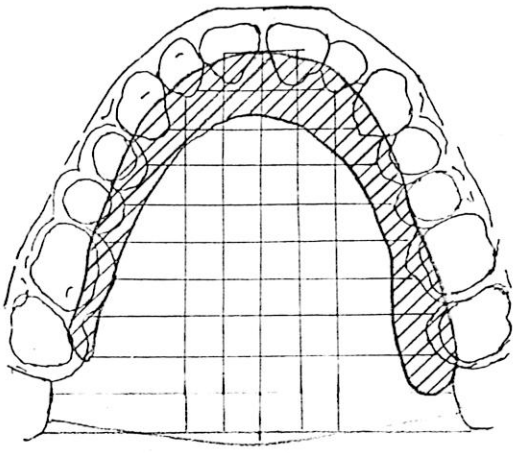


Figure IV.30. labh

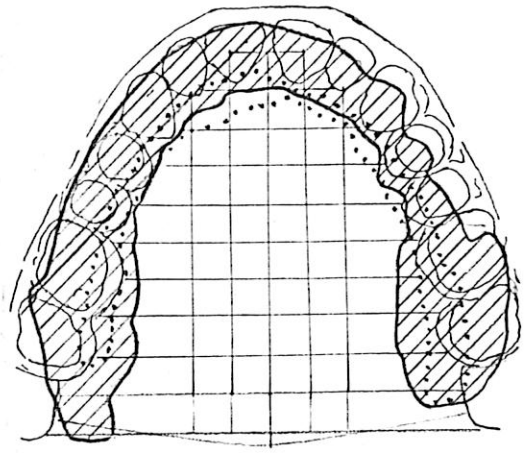


Figure IV.31ab. pala

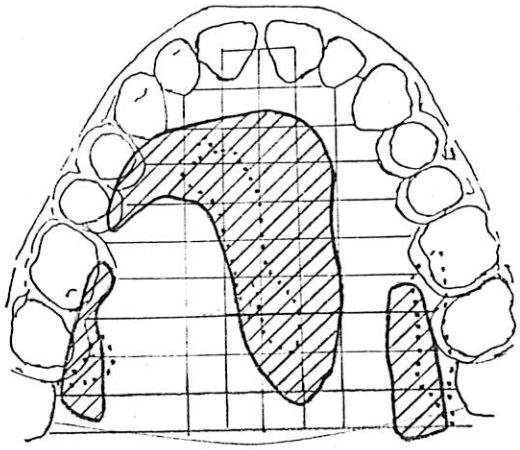


Figure IV.32ab. bạla

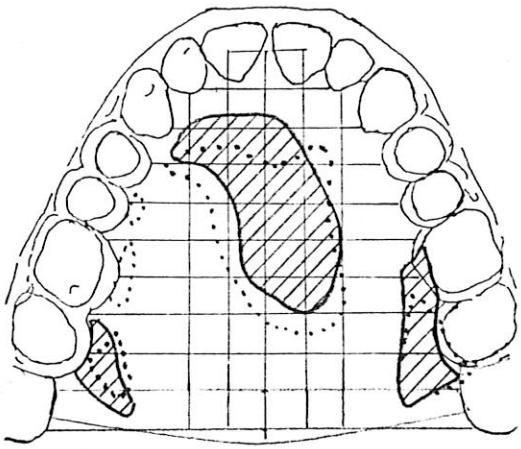


Figure IV.33ab. paḷo

Figure IV.30-33ab. Palatograms of labh, pala, bạla and paḷo.

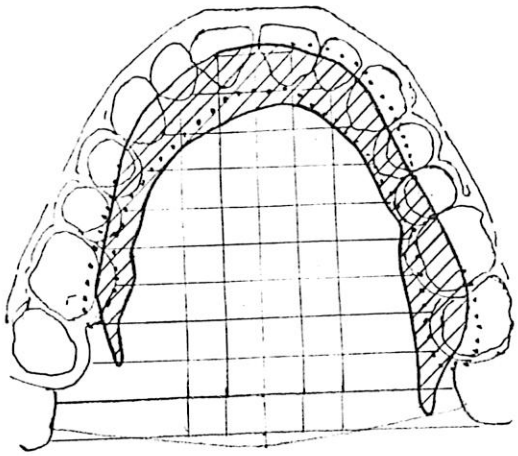


Figure IV.34ab. a. pal
b. al

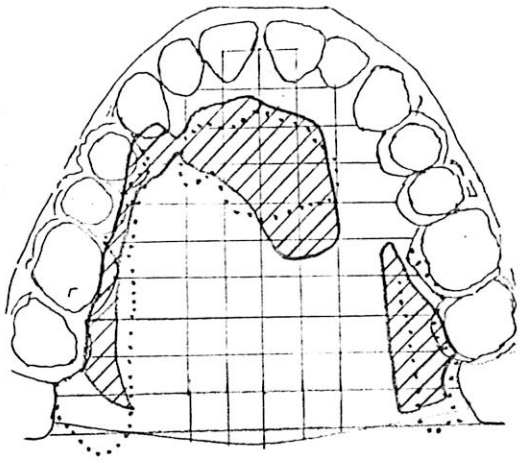


Figure IV.35ab. a. pal̤
b. al̤

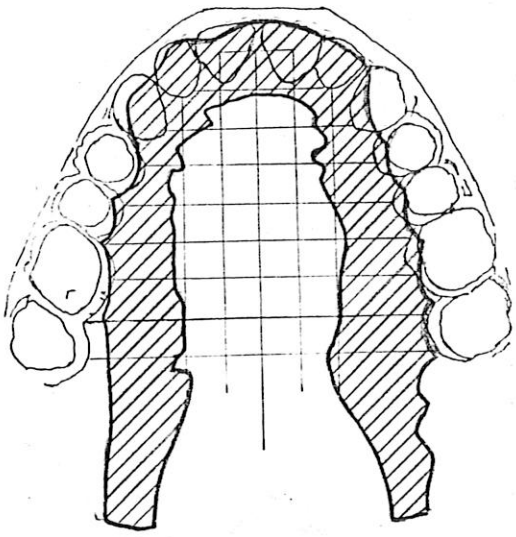


Figure IV.36. pili

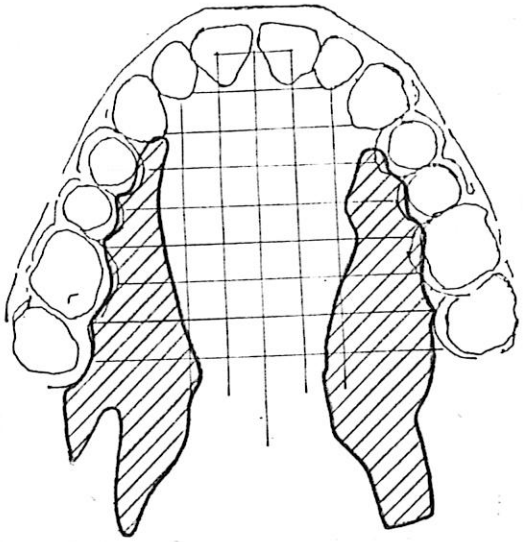


Figure IV.37. pil̤i

Figure IV.34ab-37. Palatograms of pal, al, pal̤, al̤, pili, and pil̤i.

IV.1.67. The dental n.

The palatograms of n show a rather large variation, both as regards the place of articulation and the size of the contact area. The place of articulation may be dental, denti-alveolar, or alveolar, perhaps it is most often denti-alveolar. As nasality does not show up in palatograms, n may look very similar to the dental stops or to r and l. When alveolar, it resembles r, when denti-alveolar or dental, it looks more like l and the dental stops.

IV.1.68. The retroflex flapped ɳ.

The tongue contact is in the palatal region, approximately in the area between lines 2 and 8, sometimes from 2 to 6 (Fig. IV.43b, aɳ), or even to 4 (Fig. IV.34, əphiɳi). Many times the contact is far backward at the hard palate beyond line number 8, and in some cases the ɳ has bilateral opening like l (see paɳa, Fig. IV.40 and IV.41). The retroflexed tip of the tongue comes back to its normal position very swiftly, passing through the palatal region, generally without touching the alveolar or dental zone. At times, however, it touches the alveolar region, for instance, paɳa, or baɳ (Fig. IV.41a, IV.43a).

On the whole, the flapped consonants ɾ, ɳ, ɭ, and particularly ɳ and ɭ seem to be produced with some constriction of the tongue and with a swift movement of the tongue tip, so that the contact is often rather weak.

In several palatograms (cf. paɳa, Fig. IV.41a, baɳ, Fig. IV.43a, aɳ, Fig. IV.43b), ɳ is slanting to the left side.

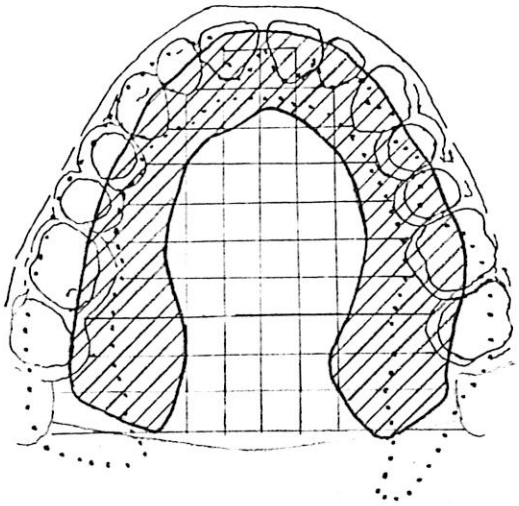


Figure IV,38ab. a. nabhi
b. nam

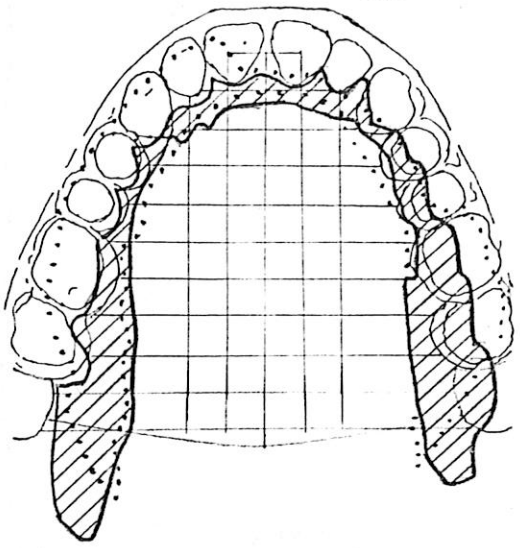


Figure IV.39ab. mana

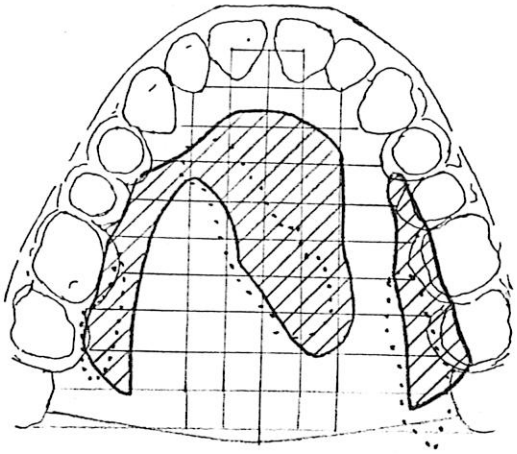


Figure IV.40ab. paṇa

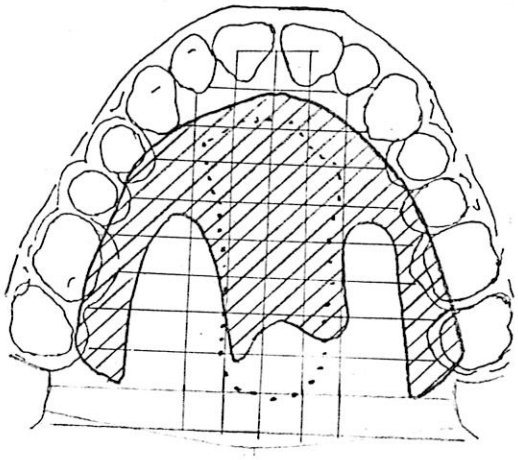


Figure IV.41ab. paṇa

Figure IV.38ab-41ab. Palatograms of nabhi, nam, mana, and paṇa.

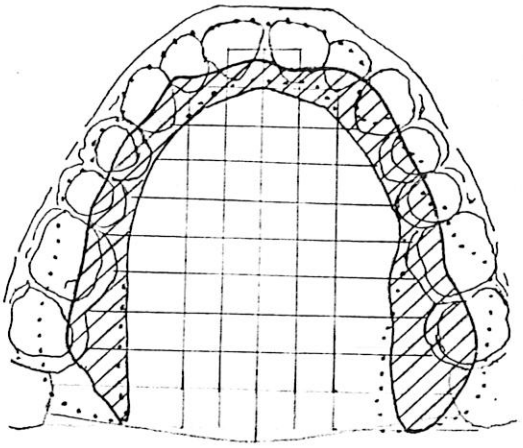


Figure IV.42ab. a. an

b. ban

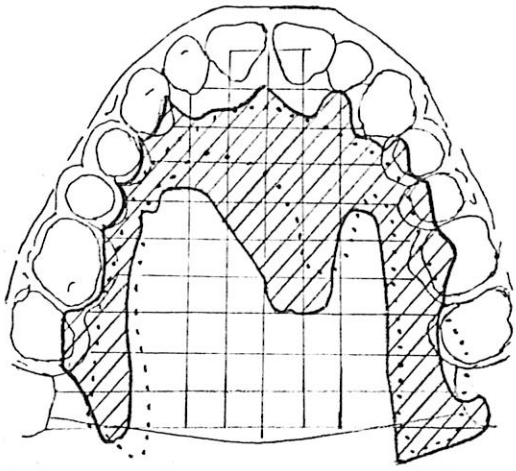


Figure IV.43ab. a. ban̩

b. an̩

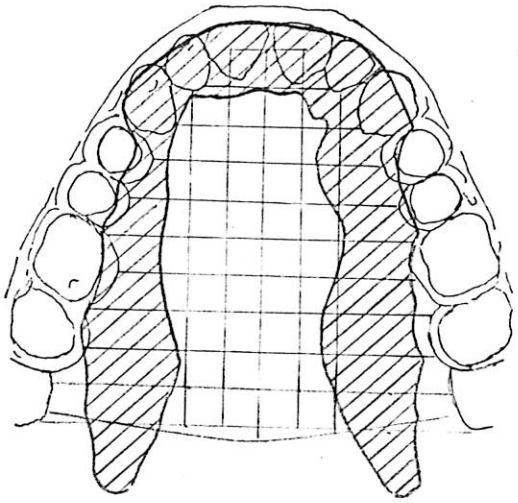


Figure IV.44. mini

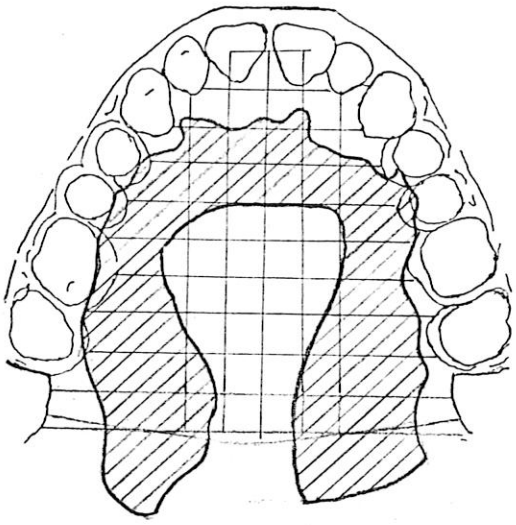


Figure IV.45. ə phin̩i

Figure IV.42ab-45. Palatograms of an, ban, ban̩, an̩, mini, and ə phin̩i.

The articulation of n̤ is influenced by the phonetic environment. It is more fronted in the context with i (see ə̤phini, Fig. IV.45).

IV.1.69. The velar stops (see Figs. IV.46a-IV.54, pp. 100-102).

Some velar stops have been investigated for comparison.

The contact area for the velar stops is in the velar region. Sometimes there is a slight contact in the region of the hard palate. Generally both k and g show contact beyond the area of line number 10 (see Fig. IV.1). It will be clear from the palatograms that g is somewhat more fronted than k, and it also covers a somewhat larger area of the palate.

Both k and g are more fronted in the environment of the front vowel i, showing contact with the hard palate (see kiki and gəgi in Fig. IV.53-IV.54). Nihalani (1974) notes a similar influence of the vowel i on the Sindhi velar stops.

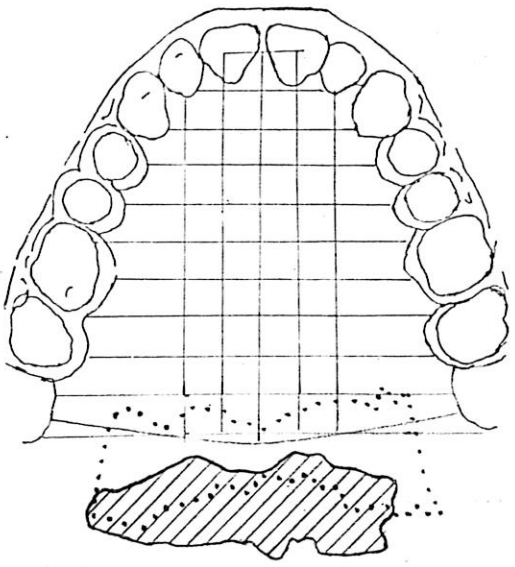


Figure IV.46ab. kap

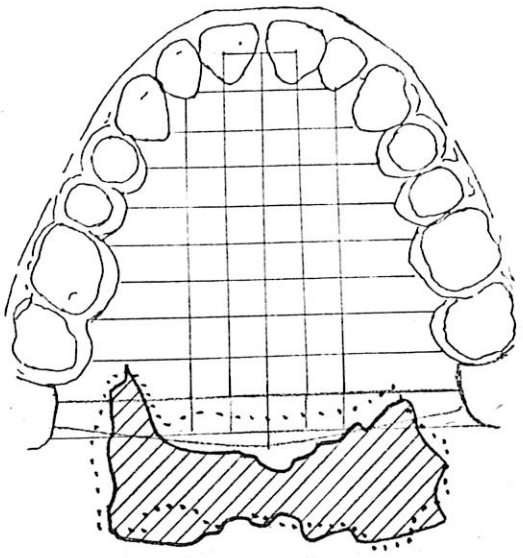


Figure IV.47ab. gaw

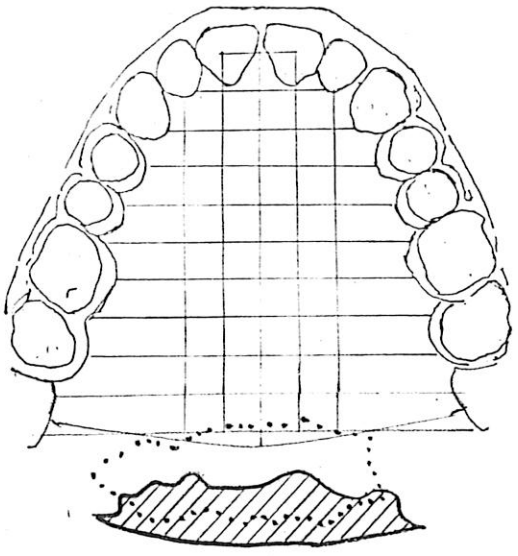


Figure IV.48ab. paka

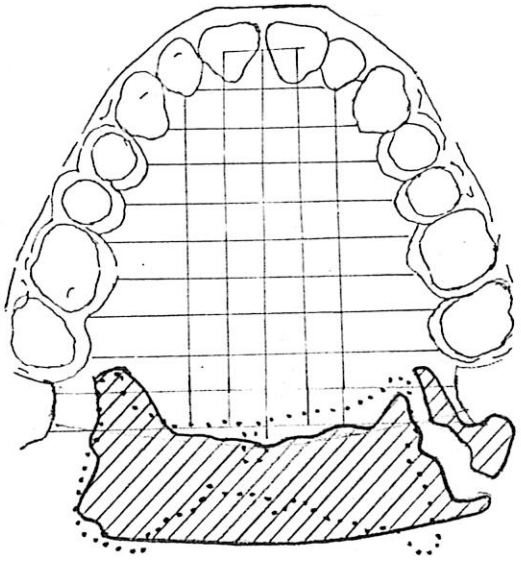


Figure IV.49ab. gəga

Figure IV. 46ab-49ab. Palatograms of kap, gaw, paka, and gəga.

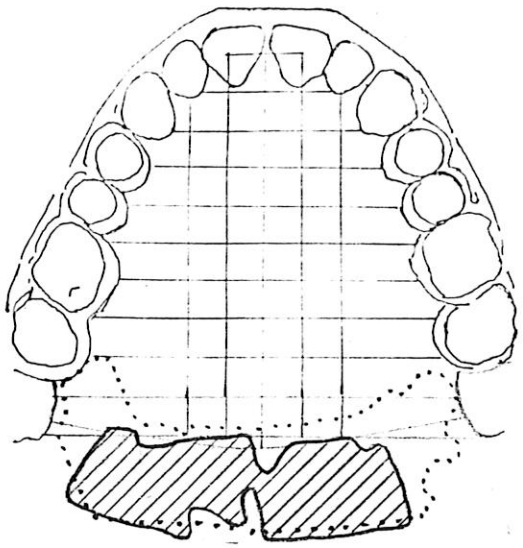


Figure IV.50ab. pak

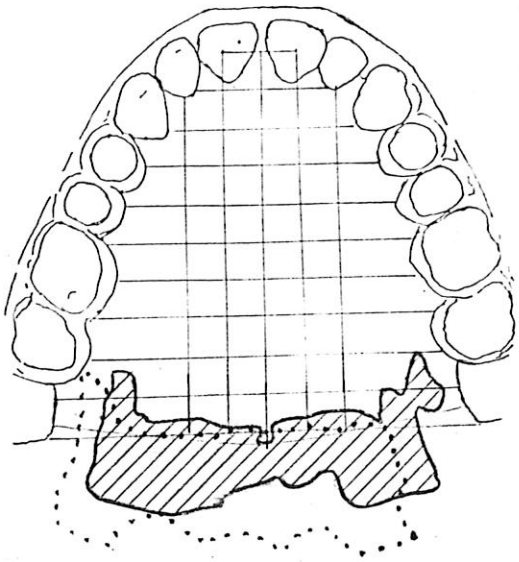


Figure IV.512b. bag

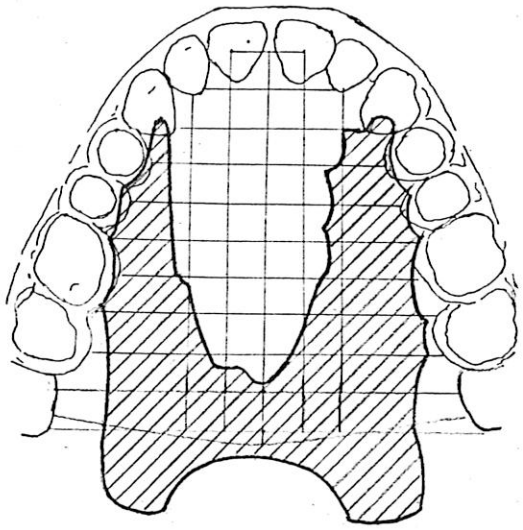


Figure IV.52. kiki

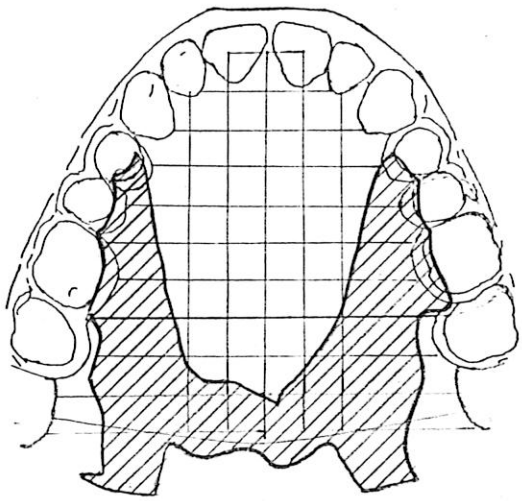


Figure IV.53. gəgi

Figure IV.50ab-53. Palatograms of pak, bag, kiki, and gəgi.

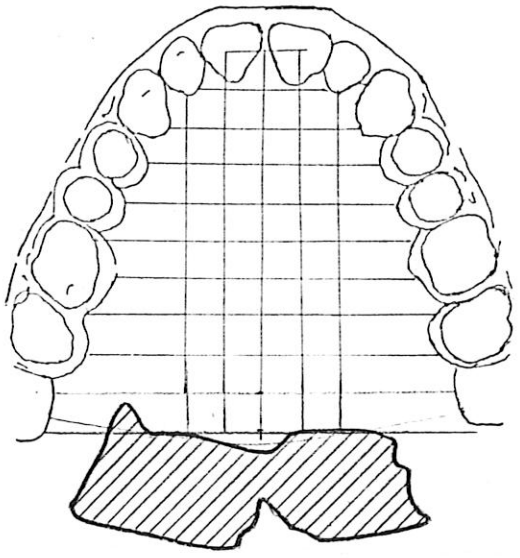


Figure IV.54. Palatogram of kuku.

IV.2. Acoustic investigation.

IV.2.1. Introduction.

Since Potter, Kopp and Green's book "Visable Speech" (1947) it has been known that consonants do not only have an acoustic pattern which is characteristic of the consonant segment proper, they also influence the acoustic pattern of neighbouring vowels, so that the part of the vowel adjacent to the consonant shows characteristic formant movements (generally called "transitions").

In a long series of papers published by the Haskins Group it has been shown that these transitions may be very important for the perceptual identification of the consonant, and that this is particularly true for stops and nasals. Stops may, in fact, in some cases be synthesized (and identified) either by means of bursts alone or by means of vowel transitions alone, although bursts and transitions are not equally good cues in combination with all vowels.

As for the stop bursts, it was shown by perceptual tests based on synthetic stimuli that bursts which are on a level with or slightly above the second formant of the vowel are heard as velars. Other bursts are heard as dentals (or alveolars) if their frequencies are above approximately 3000 Hz, otherwise as labials (Cooper et al. 1952). The perceptual importance of the transitions of formant 1 and 2 was demonstrated in 1952 (see e.g. Cooper et al.), whereas the importance of formant 3 transitions was demonstrated in some later articles (see Harris et al. 1958, and H.S. Hoffman 1958). It was found that F_1 transitions mainly indicate manner of articulation (a lower start is a cue for voicing),

whereas the transitions of higher formants indicate place of articulation. In the first experiments it was shown that vowels starting with a rising F_2 were heard as labial stop + vowel, and vowels with a falling F_2 as dental or velar stop + vowel with the distribution that a steep fall favoured t-d judgements before u o ɔ, and k-g judgements before i e ɛ, whereas a slight fall had the opposite result. A falling F_3 was found to favour the preception of dentals, whereas labials and particularly velars required a rising F_3. These transitions are caused by the changes in cavity resonances which take place when the articulators move from the consonant to the vowel position and vice versa, therefore consonants articulated at the same place (i.e. p,b,m, or t,d,n, or k,g ŋ) produce the same transitions and, if the initial and the final consonant in a CVC syllable are the same, the transitions will normally be symmetric. Fig. IV.55 gives a schematic picture of the first three vowel formants in the syllable gʌg (cp., e.g., Potter, Kopp, Green 1947, p. 102).

(g) ʌ (g)

Figure IV.55. Schematic picture of vowel formants.

If the formant movement is described in the time dimension, F_1 will be designated as rising after g and falling before g, but this formulation is slightly misleading because it does not bring out the fact that the rise and fall are two aspects of the same fact, namely that the first formant of ʌ is lowered by a neighbouring g. The direction of the transition is therefore now generally described as seen from the steady state part of the vowel, and transitions having a downward direction are called negative, whereas those that have an upward direction are called positive. F_1 and F_3 of ʌ are thus said to have negative transitions in combination with g, whereas F_2 has positive transitions in this position.

This formulation is more general than the formulation about "rising" and "falling" transitions, but it is not sufficiently general, since it does not cover all vowels. F_2 of u will, for instance, have a positive transition in combination with d, whereas, F_2 of i will have a negative transition, and what matters is not really the direction of the transition but the fact that it points to a definite consonant resonance. If this resonance is lower than the steady state vowel formant the transition will be negative, if it is higher it will be positive, cf. Fig. IV.56 showing the direction of F_2 transitions of different vowels after d:

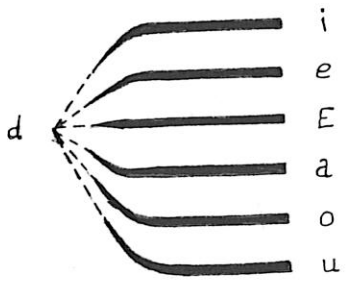


Figure IV.56. Schematic F_2-transitions after d.

Potter, Kopp and Green (1947) already emphasized this aspect, talking about the "hub" of a consonant, defined as its visible or hidden resonance, but the idea was developed further by the Haskins group in the form of the "locus" concept (see Delattre et al. 1955). The locus is a point at the frequency scale to which the transitions of the different vowels point. The formant 2 locus was found to be at 1800 Hz for dentals, 3000 for velars, and 720 for labials (Delattre et al. 1955). It is emphasized that the transitions do not start at the locus, they only point to the locus, which can be found by extrapolation of the transitions (see the dotted lines in Fig. IV.56). This was no doubt an oversimplification. Various scholars have emphasized that only dental consonants can be expected to have a fixed resonance. In the case of labials and velars there may be different degrees of coarticulation which will give a variable consonant resonance; for instance, the tongue may anticipate the position of the following vowel during a labial consonant; the point of articulation of a velar may be influenced by the following vowel, and the lips may be rounded in anticipation of a following vowel and thus lower the resonance of the consonant (see, e.g., Eli Fischer-Jørgensen 1954 and 1957, Stevens and House 1956, and Öhman 1966). The Haskins group also had difficulties with the velar locus. The locus at 3000 Hz functioned for front vowels only, not for back rounded vowels. In his answer to the critics Delattre stressed that the locus was not meant to indicate the resonances of consonants (or convergence points of transitions) in actual speech. This resonance is modified by coarticulation. In the case of back rounded vowels after velars the transitions do not point to the locus. The locus is defined as the frequency

towards which the formant transitions must point in order to contribute maximally to the perception of a given place of articulation (Delattre 1969). It thus becomes a rather abstract concept.

More recently it has been emphasized by K.N. Stevens and by Gunnar Fant that bursts and transitions should not be described as separate cues, but as a single integrated auditory stimulus (Fant 1968, p. 258, Stevens (1973, p. 160), and Stevens et al. (1976), and that the first 20 ms after release of a stop consonant are most important for perception.

A good deal of perceptual investigations of stops and nasals, and some on liquids have been published during the last twenty years. Papers based on acoustic analysis of real speech have been less in number. We are, however, pretty well informed about the acoustic properties of labial, alveolar (and dental) and velar consonants, whereas little has been published on retroflex consonants, except for the retroflex American r and American vowels with retroflex modification, which are generally known to be characterized by a low F_3.

Jakobson, Fant, Halle (1952, p. 49) reproduce a spectrogram of Bengali ṣ with the comment that "the retroflex consonant has energy in a lower frequency region and affects the third formant of the following vowel in a downward direction."

Fant (1968, p. 239) remarks very briefly that in retroflex modification with alveolar point of articulation F_4 is low and close to F_3, whereas with palatal point of articulation F_3 is low and close to F_2.

Ramasubramanian and Thosar (1971) have analysed a restricted number of Tamil retroflex ṭ, ṇ, and ḷ. They give formant values for the steady state of ṇ and ḷ (ṇ F_1 280, F_2 1400, and F_3 2400; ḷ F_1 280, F_2 1450,

and F_3 1600), but they do not indicate the transitions. They have furthermore tried to synthesize retroflex consonants with 3 formants in combination with i, u, and a including transitions, and arrive at some values for the loci. But their tables contain various mistakes or misprints and are therefore somewhat difficult to judge. A main result is, however, that F_3 is rather close to F_2.

A very important contribution to the acoustic description of retroflex stop consonants has been given by K.N. Stevens and S. Blumstein (1975). They show spectrograms of the syllable ata spoken by three Hindi speakers. There is an initial burst of 2700-3000 Hz associated with F_3 or F_4 of the following vowel. F_2 has a positive transition, and F_3 a negative transition in the preceding vowel and sometimes in the following vowel. Evidence for a lowered F_4 has also been found in some cases in either the preceding or the following vowel. The corresponding dental stop has a somewhat higher burst and no negative transition of F_3. Moreover, an extensive perceptual test has been made using stimuli changing in 13 steps from a dental consonant via a retroflex consonant to a velar consonant. The first stimuli varies in the start of F_3 and in the frequency of the burst, which were both gradually lowered, the last stimuli in the frequency of the burst only. The perceptual limit between dental and retroflex consonant turned out to be approximately at the point where F_3 changes from positive to negative transition, and the limit between retroflex and velar consonants at the point when the burst comes close to F3. We will return to the theoretical parts of the paper at the end of this chapter.

IV.2.2. Informants.

The informants of the present study were RD and RT (for their data, see III.2.1). RD is the main informant. For RT a somewhat smaller number of spectrograms were taken, and only stops in intiial position have been measured, but the spectrograms of stops in other positions and of nasals and liquids have been inspected visually and compared with the results for RD.

IV.2.3. The material.

The word lists used are given in Appendix C . All lists (I-IX) were used for spectrographic analysis. Lists II and IIIa contain velar consonants, the others dental and retroflex consonants (nasals, liquids, and unaspirated stops). List I is a preliminary list. List II is the main list; it contains dental and retroflex consonants in all positions in combination with the vowel a. Lists II-VII contain the same consonants in combination with other vowels, but in intervocalic position only. Lists I-VII were spoken by both informants in Copenhagen in 1967. Lists II, III, and VII were spoken again by RD in Copenhagen in 1977. Lists IIa, IIIa, VIIa, and IX were added in Copenhagen in 1977 and spoken by RD only. List VIII was recorded in Cornell University by RD. A list with VCV syllables was also spoken by RD in Copenhagen in 1977, but only a few words from this list were utilized. Lists VIII and IX consist of nonsense syllables, the other lists contain real words.

Spectrograms were taken of one reading of each list (but for Lists II, III, and VII both the 1967 and 1977 readings were analysed). Lists

VIII and IX (which were added in 1977) contain only initial stop consonants. There is thus a larger number of examples with initial stops than with stops in other positions, and with nasals and liquids. The reason is that it was difficult to see a clear difference between dental and retroflex consonants in initial position, so that more examples were considered necessary. List VIII was recorded specifically for the investigation of bursts.

IV.2.4. Methods of analysis.

The material was recorded on a professional tape recorder in a sound treated room, and the whole material was used for spectrographic analysis.

The spectrographic method has been explained in details in chapter II.4.2. The spectrographic investigation of the consonants was undertaken in the Institute of Phonetics of the University of Copenhagen. Spectrograms of the material recorded in 1967 were taken in 1967-68, using a new Kay Electric Sonagraph which was considerably better than the old one used for the analysis of vowels. The material recorded in 1977 was analysed by means of another Kay Electric Sonagraph which had just been purchased. It was not yet working quite satisfactorily: in particular, the base line was too dark and interfered with the picture of F_1 of high vowels in wide band spectrograms. The illustrations have, therefore, been taken mainly from the 1967 recording.

As a rule both wide band and narrow band spectrograms were taken of each word. Very often two or three wide band spectrograms with different intensity and different degrees of compression were taken in order to get a clear picture of both formants and bursts in stop consonants.

The spectrograms were used for the measurement of formant transitions. In order to specify the transitions both the frequency of the steady state vowel formants and the end points of the transitions were measured together with the duration of the transition. This latter measure is not very exact since the boundary line between transition and steady state is rather arbitrary in many cases. Averages of the transition durations are therefore not given in the tables, but the measurements have been used for the statement of clear differences in transition length (e.g. the rather brief transition of F_4) and for the drawing of schematic spectrograms.

A rough analysis of the bursts was also undertaken on the basis of wide band spectrograms. A more exact analysis might have been undertaken by means of sections, but that would have required segmentation of burst and vowel (electrically or by tape cutting), which would have taken much time. Instead acoustic analysis of the bursts and the start of the vowel was undertaken in the laboratory of Professor K.N. Stevens at MIT, based on a computer directed linear prediction analysis. This was done with the help of Professor Stevens.

A detailed technical description of the computer program is given in V.W. Zue (1976). It is based on a speech production model containing a source and an all-pole filter representing the combined effect of the glottal source, the vocal tract resonances, and radiation losses. The zeros found in nasal consonants can be approximated by means of poles. By means of linear prediction (in this case using a form of autocorrelation analysis) a best fit is found between the incoming signal and the smoothed curves generated by the computer. The frequency band analysed

is restricted to 5000 Hz, because most of the interesting characteristics of the speech wave are found below 5000 Hz, and because a filter including higher frequencies would give various complications. The time window was 25.6 ms wide. It is symmetric and has a smooth bell-like shape which means that signals found at the sides are recorded with decreasing intensity. Because of this shape the effective width of the window is somewhat narrower. See Fig. IV.57, which is a sketch drawn by Professor Stevens (Personal Communication).

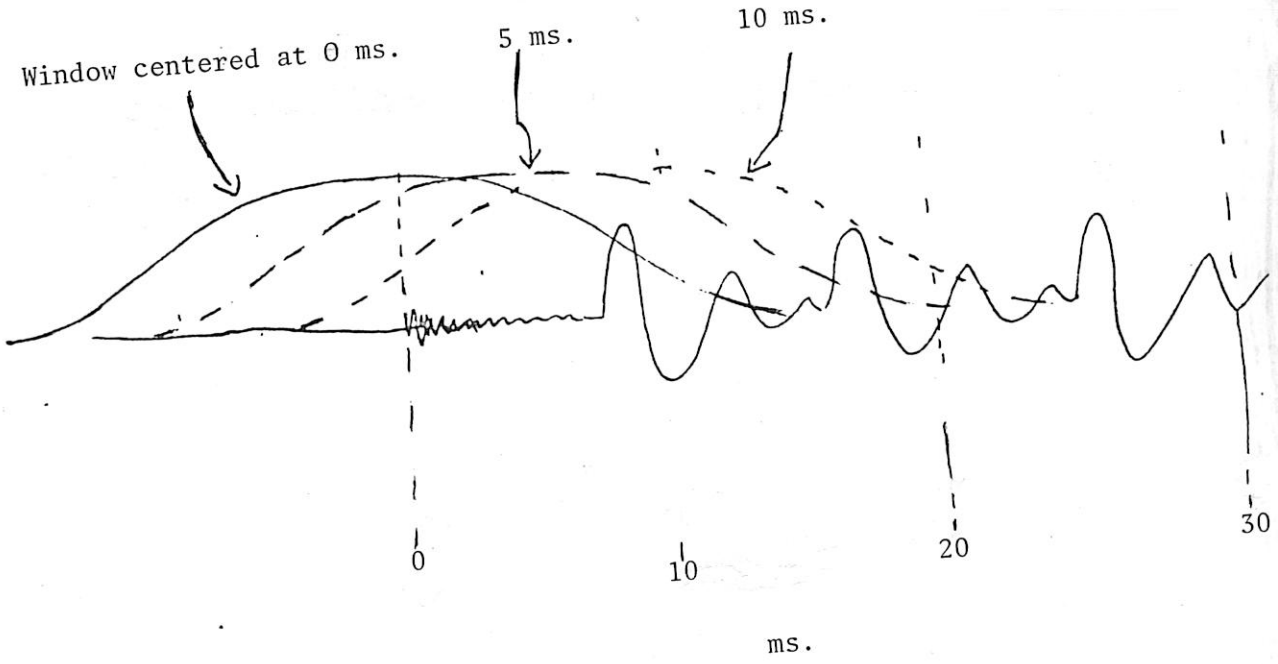


Figure IV.57. Sketch of the windows used in the linear prediction analysis (K. Stevens).

The window can be moved in steps of 5 ms. The first point, designated as zero, is placed in such a way that the top of the window is at the start of the burst. If the distance from burst to vowel is less than half the window, i.e. 12.8 ms. as in this picture, the spectrum will also be somewhat influenced by the start of the vowel formants, and the spectra taken at the following two points (5 and 10 ms) will also be influenced by both burst and vowel, but increasingly by the vowel formants. If the distance is more than 12.8 ms, it is possible to get a separate spectrum of the burst. A hard copy reproduction of the curves can be made, either one curve at a time (as in Fig. IV.58a), or curves from a number of consecutive points together, as in Fig. IV.58b. In Fig. IV.58b it can be seen that the first two curves (taken at points 0 and 5) have a maximum around 1300 Hz due to the burst, whereas the last (point 10) has a maximum of 550 Hz. corresponsing to the first formant of o.

By this method a number of consonants in initial position have been analysed, namely the stops of lists II-VII spoken by RD and RT, and list VIII spoken by RD. In most cases points 0, 5, and 10 have been recorded together. The main purpose was to find the relevant differences between the bursts in dental and retroflex stops. However, due to the length of the time window the zero curve will only indicate the burst alone in voiceless stops where the distance between burst and vowel is sufficiently large. (In some cases of retroflex stops, there will be a slight influence from the vowel formants because the distance is somewhat shorter in these stops than in the dental stops, see IV.2.52). As for the voiced stops, the curve at point zero will always comprise both burst and vowel start. Therefore only the curves of voiceless stops have

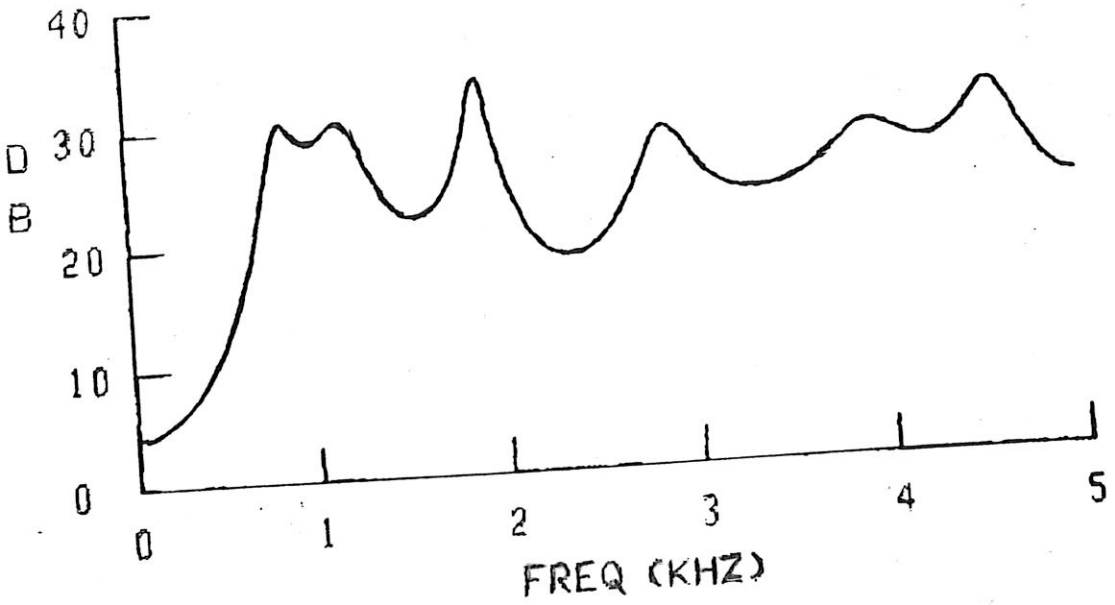


Figure IV.58a. Linear prediction analysis of te at point 0 (RD).

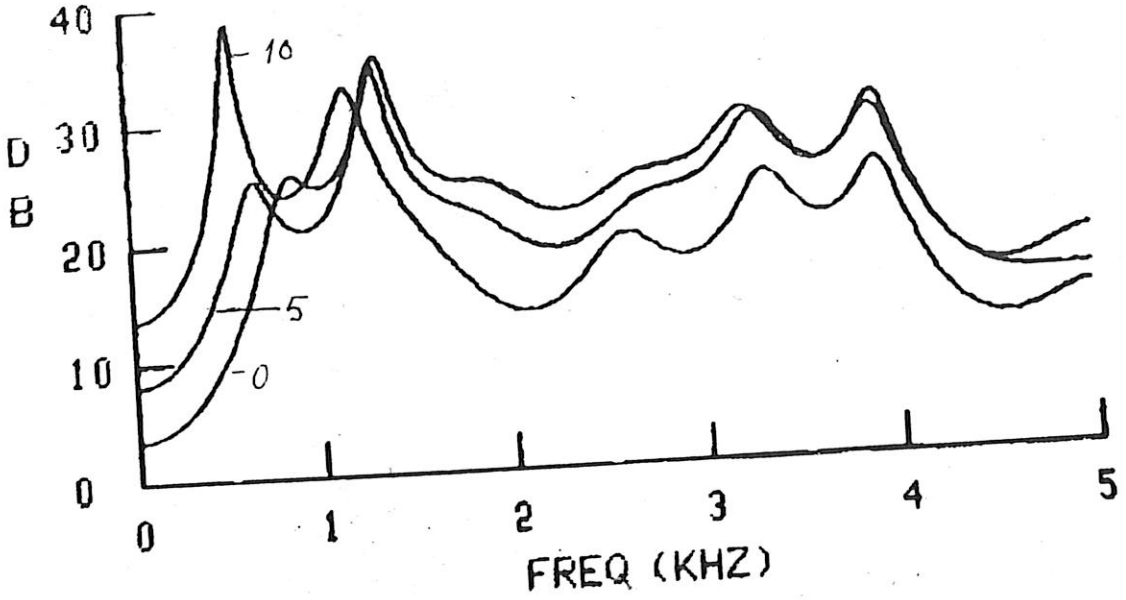


Figure IV.58b. Linear prediction analysis of to (in roto) at points 0, 5, and 10 (RD).

been utilized for this purpose. (For the purpose of Professor Stevens, this difficulty is not so important because he is mainly interested in seeing the integrated effect of burst and vowel start.)

Moreover, the curves taken at point 10 (or sometimes 15) have been compared with the spectrographic measurements of the start of the transition. The agreement is quite good except for the first formant of the high vowels i and u, for which the linear prediction analysis often gives much higher frequencies. For instance, by the spectrographic analysis the first formant of these vowels was found to have a frequency around 300 Hz, whereas the frequency according to the linear prediction analysis is often 400 Hz. This may partly be due to the fact that spectrographic measurements are based on peaks in the acoustic curve, whereas the linear prediction analysis is based on a theory of poles in the vocal tract. This may give some differences in the results for very low formants. There may, perhaps, also be mistakes in the linear prediction curves, for an F_1 of 400 Hz for i seems to be too close to the F_1 of e, which is generally 450-500 Hz, corresponding to the results of the spectrographic anslysis. There are also some differences in formant 4 and the higher peaks of the bursts. Generally the values obtained by the spectrographic method sre somewhat higher.

However, the measurement of formant 4 was particularly difficult because there are cases of split formants or weakened formants. Generally RD has a formant 4 around 3700 Hz and a formant 5 around 4200 Hz, and in some cases of a and o also a (weaker) formant around 3100 Hz. F_5 is often too weak to show up in the spectrograms, and this also happens to F_4, and sometimes it is difficult to decide which one it is, particularly

since they may all be lowered in rounded vowels, or very weak, or missing in those vowels. Moreover, it is not always evident from where the transition - which has been called F_4 transition - starts. There are, therefore, certainly some inconsistencies in the measurements. In some other cases it has also been difficult to decide the formant number and exclude possible spurious formants. There have been many points of doubt, but the cases have been carefully considered.

Only RD's spectrograms have been measured, but RT's spectrograms have been compared with those of RD by visual inspection.

A binomial pair test has been used to test the signifficance of the differences between dental and retroflex consonants (see Sidney Siegel, 1956, table pp. 36-37, 250).

IV.2.5 Results.

IV.2.51. Liquids and nasals.

As mentioned in II, the retroflex liquids and nasals (ṛ, ḷ, and ṇ) are not found initially, so that the contrast to the dentals is restricted to the medial and final positions. Only RD's consonants have been measured.

A. r and ṛ

The consonantal section.

Initial r is a one-tap-ṛ. There are only two examples in the text (two readings of rab); they have the average formants 550, 1537 and 2450.

In final position both r and ṛ have a single tap or flap. There are three examples of each one in the text, all after a-. There is a consistent difference in the formants, the second formant of ṛ being slightly higher and its third formant lower than the corresponding formants of r. The averages are for r: 600, 1442, and 2425, for ṛ 515, 1572, and 2188. The differences in F_1 are not consistent.

Medial r and ṛ are both flaps with a very short closure phase. The duration is 21 ms for r, and 13 ms for ṛ. During the closure no formants are seen in the spectrograms except for a low resonance around 250 Hz. There are, however, two exceptions: boro, which has a second formant at 1250 Hz, and one reading of əmiri, with formants at 300 (?), 2100, 2630, and 3750.

Formant transitions in adjacent vowels.

In the case of medial r and ṛ, the transitions of the adjacent vowels are the only features that are visible in the spectrograms, apart from the short pause. The transitions following initial r (rab) differ from those following medial r by having a very long and extensive transition of F_3 (1850-2263, of 120 ms duration). F_2 shows a transition of 55 ms duration (1425-1363).

As for the transitions preceding the final consonants, they do not differ from those preceding the medial consonants, and the averages have therefore been combined. Table 2 of Appendix D gives the frequencies of start and end point of the transitions and the extent of the rise or fall (+ and - indicate "positive" and "negative" transitions). Schematic

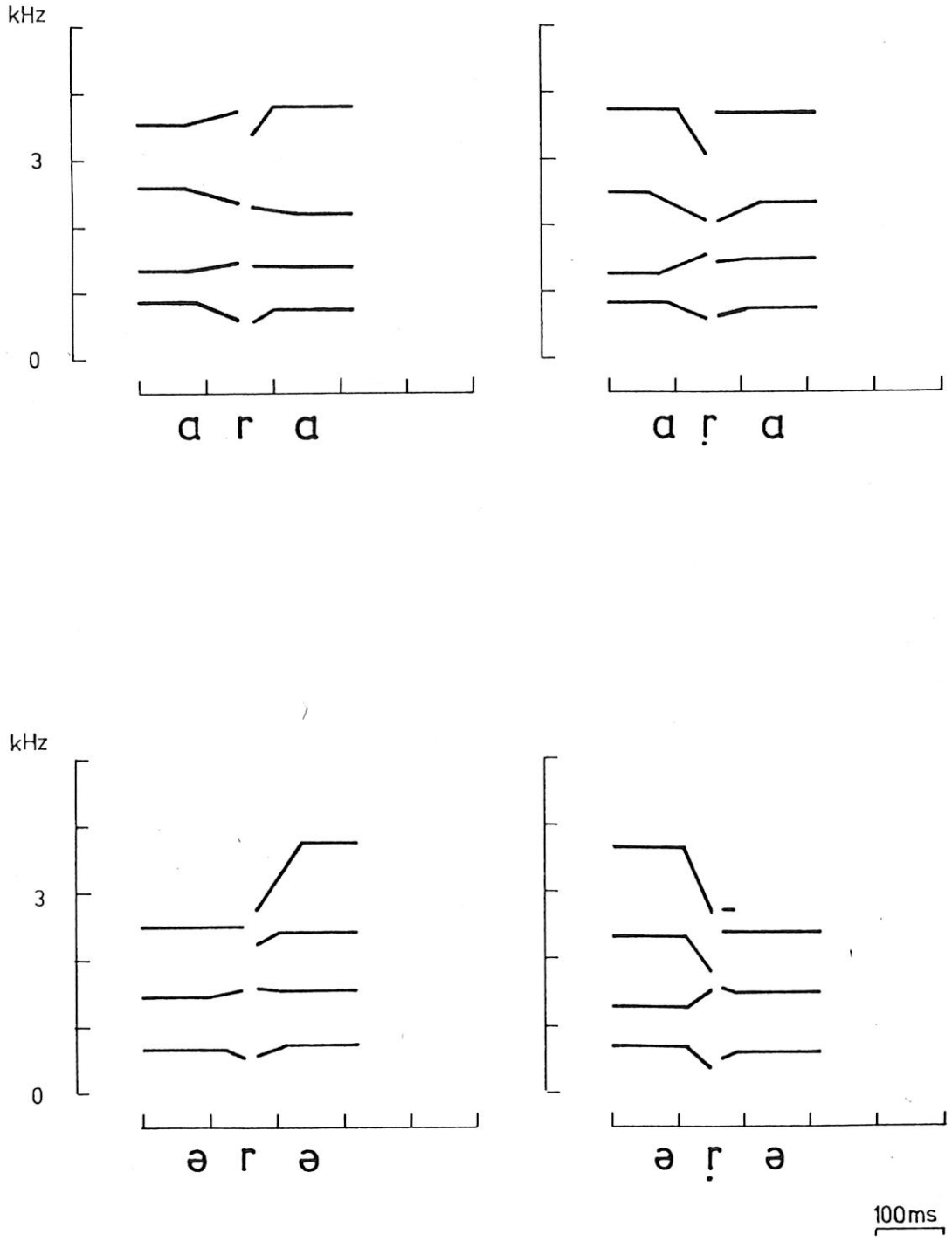


Figure IV.59. Schematic drawings of formant transitions.

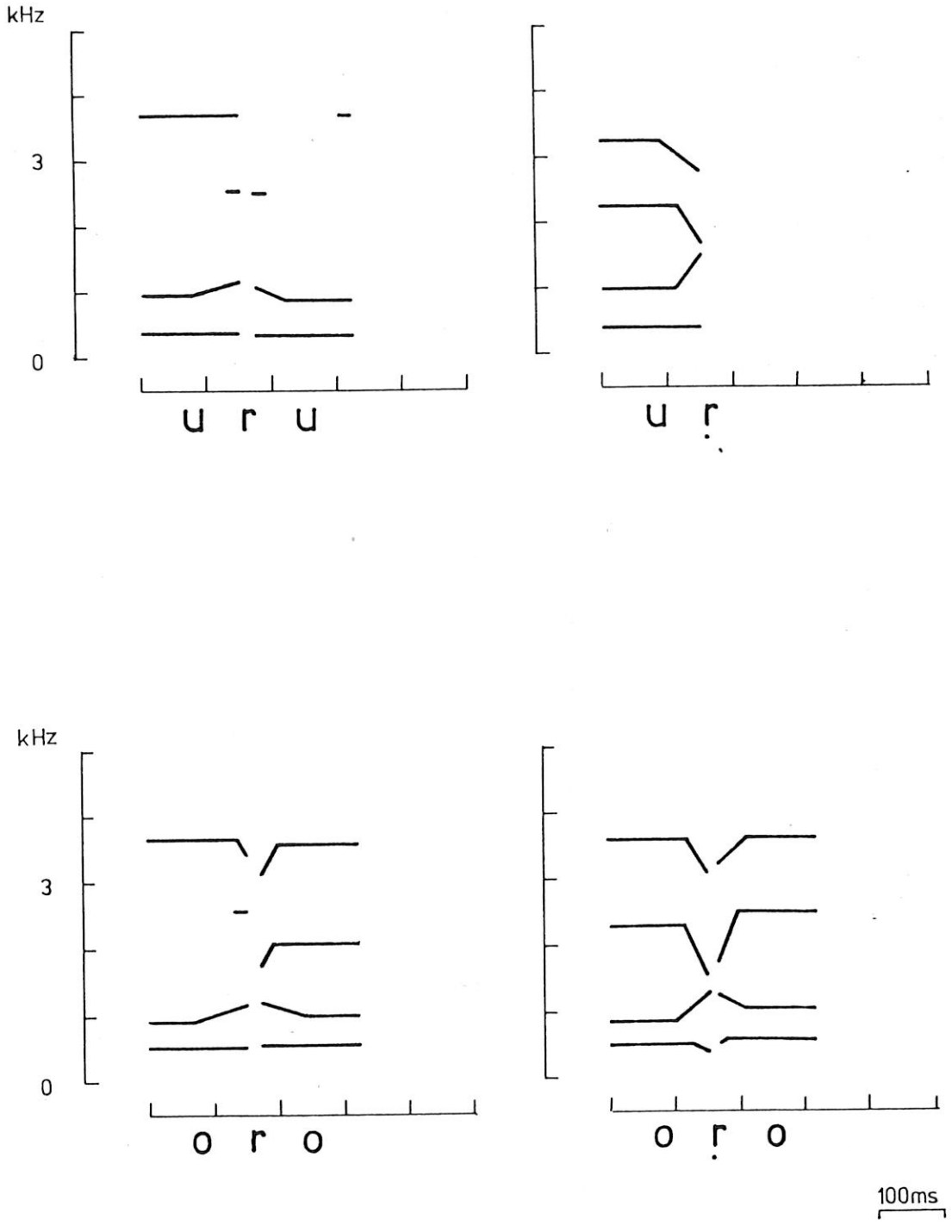


Figure IV.60. Schematic drawings of formant transitons.

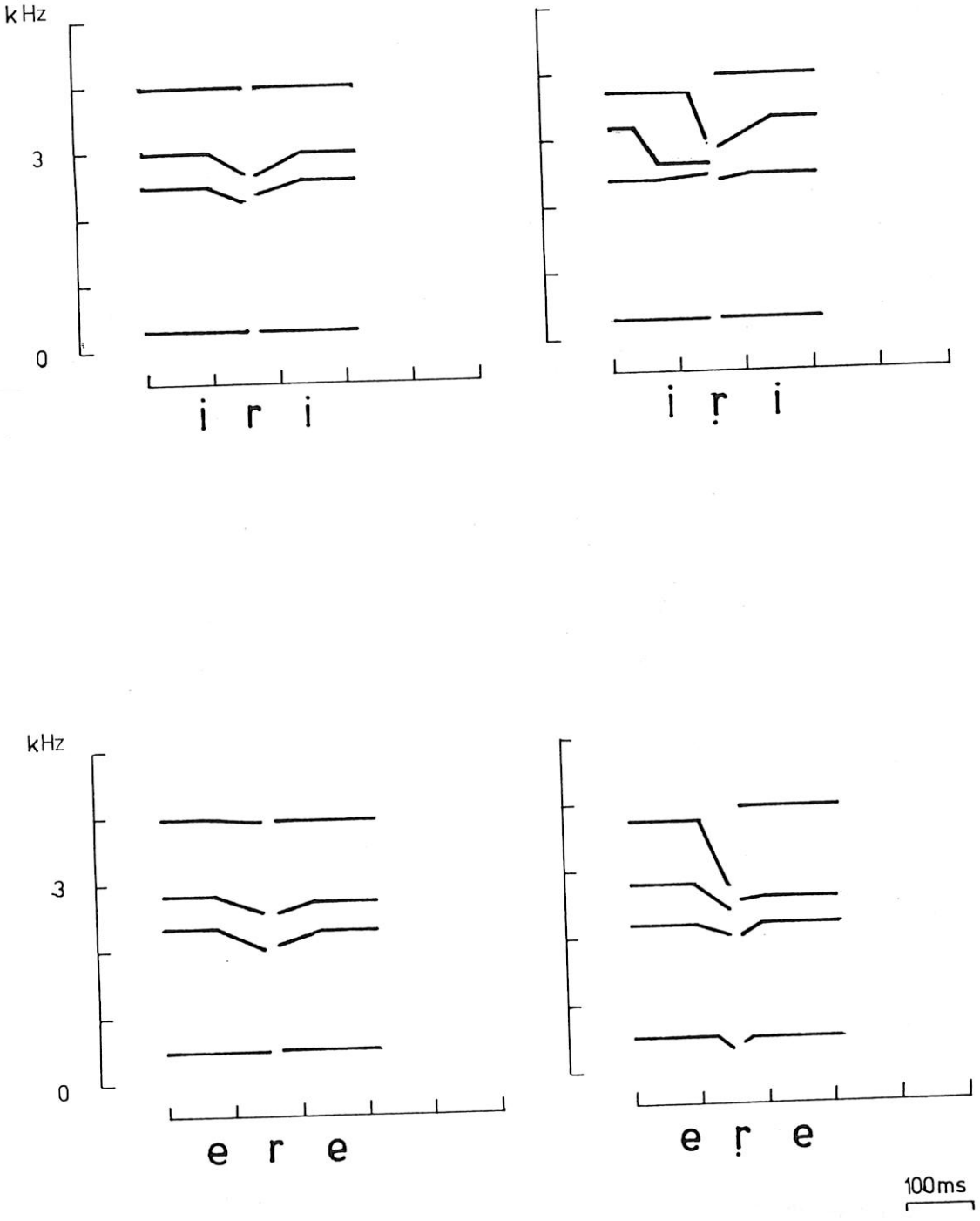


Figure IV.61. Schematic drawings of formant transitions.

drawings are given in Figs. IV.59-61 and IV.63-64, and some specimens of spectrograms in Fig. IV.62. The averages of vowel transitions of preceding and following a are based on 7 and 6 examples, respectively. For the other vowels there are only 1-2 examples.

It appears from the tables and figures that there are no consistent differences between vowel transitions after r and ṛ. Both have in most cases a clearly negative F_3, and in some cases a negative F_4.

The transitions of the preceding vowels are, however, clearly different. Both F_3 and F_4 are strongly negative before retroflex ṛ. F_2 is positive both before r and before ṛ, but it goes somewhat higher up before ṛ. The most relevant measure is probably the frequencies of the end points of the transitions. They differ for both formants 2, 3, and 4, the vowels before retroflex consonants having a higher frequency of formant 2, and a lower frequency of formants 3 and 4 than before the dental consonants. These differences are very consistent. For F_3 and F_4 there are no exceptions when the single words are compared in pairs (there are 11 and 12 comparable pairs, respectively); for F_2 the difference is found in 10 out of 13 comparable pairs. The differences are significant at the 1% level. The frequency of F_4 of the steady state part of the vowel preceding retroflex ṛ is also generally lower than the steady state part of the vowel preceding dental r, whereas F_3 varies. The transitions of F_4 in vowels preceding a retroflex ṛ are very often very steep, and start slightly later than those of F_3. In e and i the F_3 transition takes place in the middle of the vowel, the F_4 transition at the end (see Fig. IV.62).

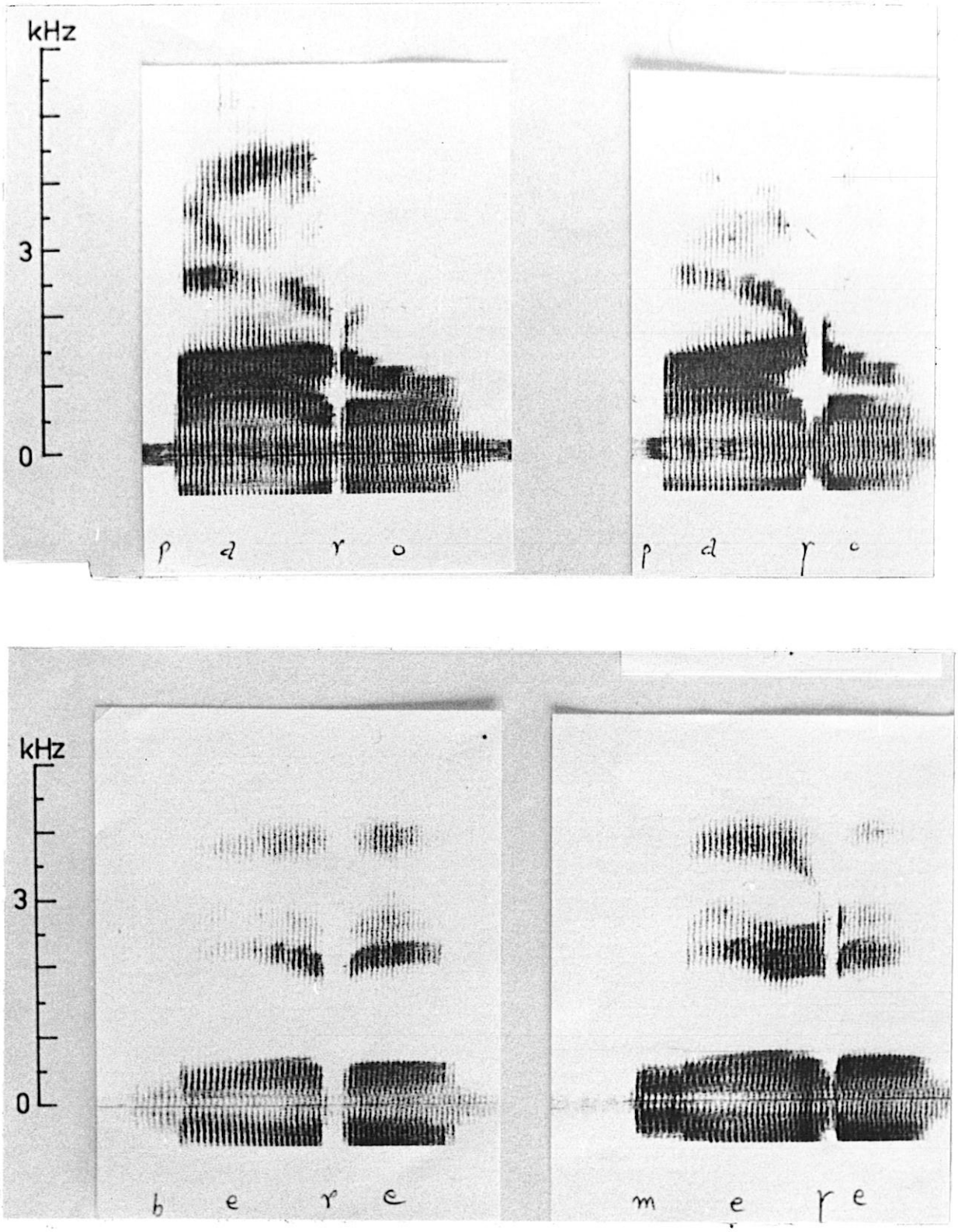


Figure IV.62. Spectrograms with paro, paro, bere and mere (RD)

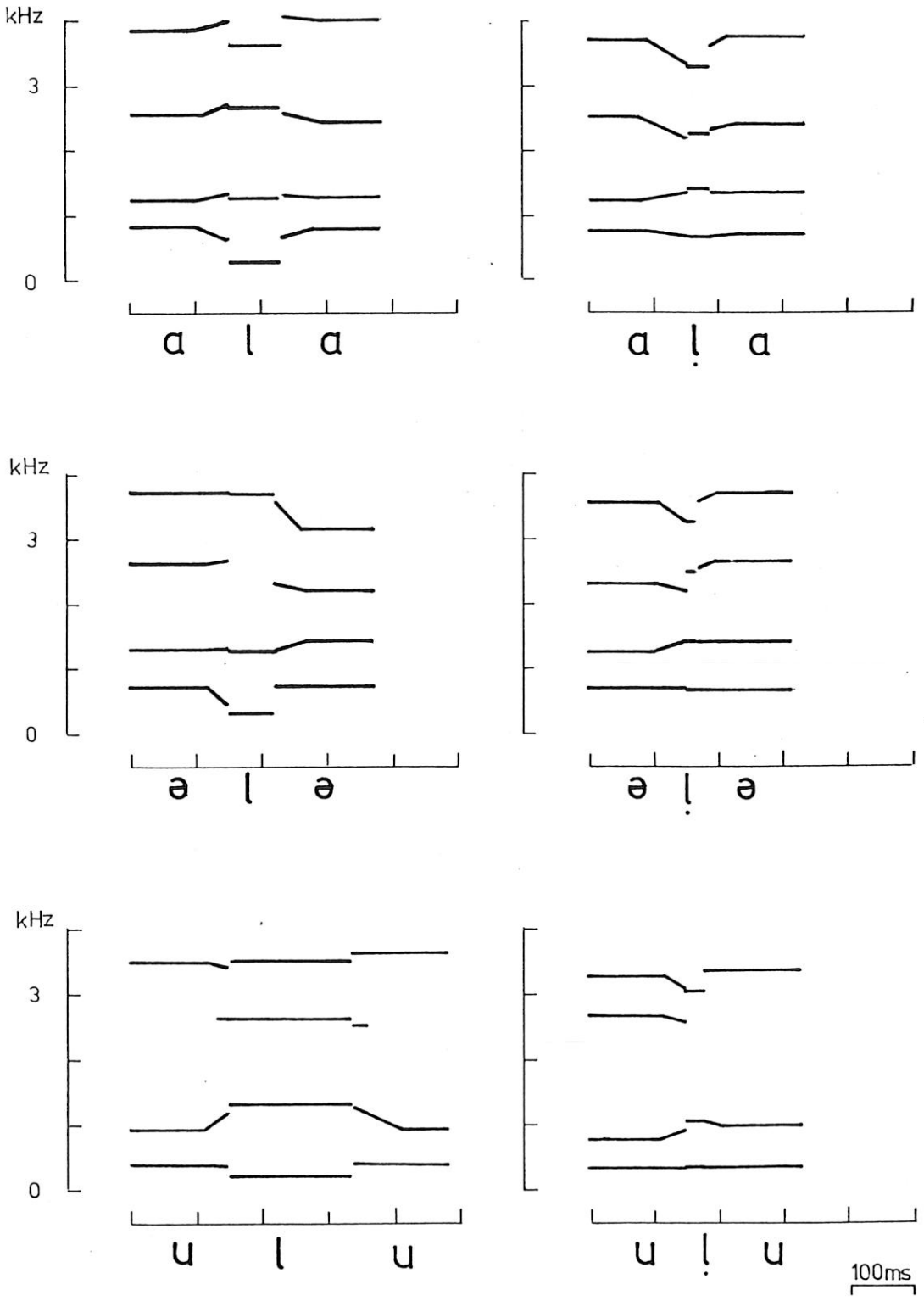


Figure IV.63. Schematic drawings of formant transitions.

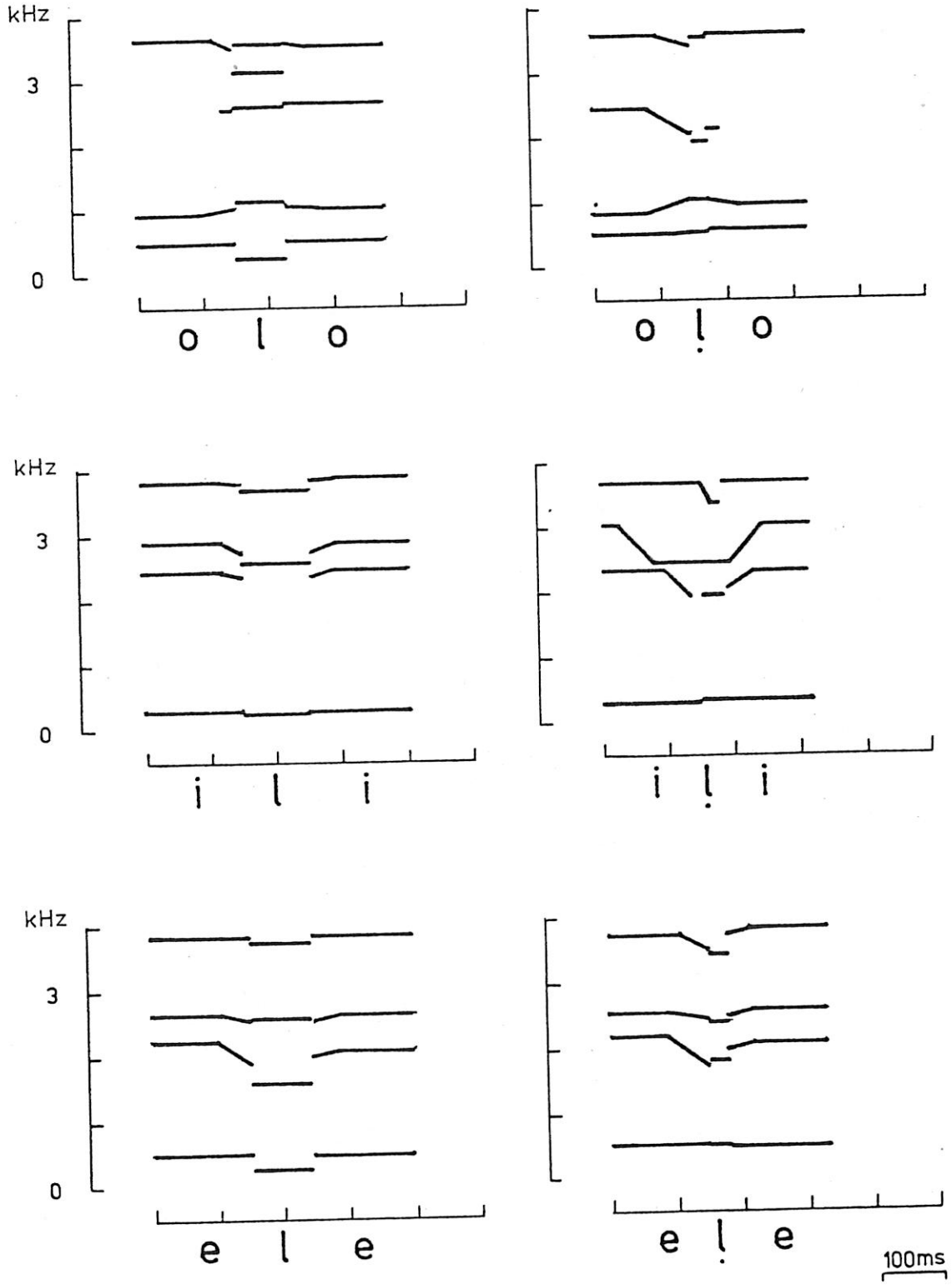


Figure IV.64. Schematic drawings of formant transitions.

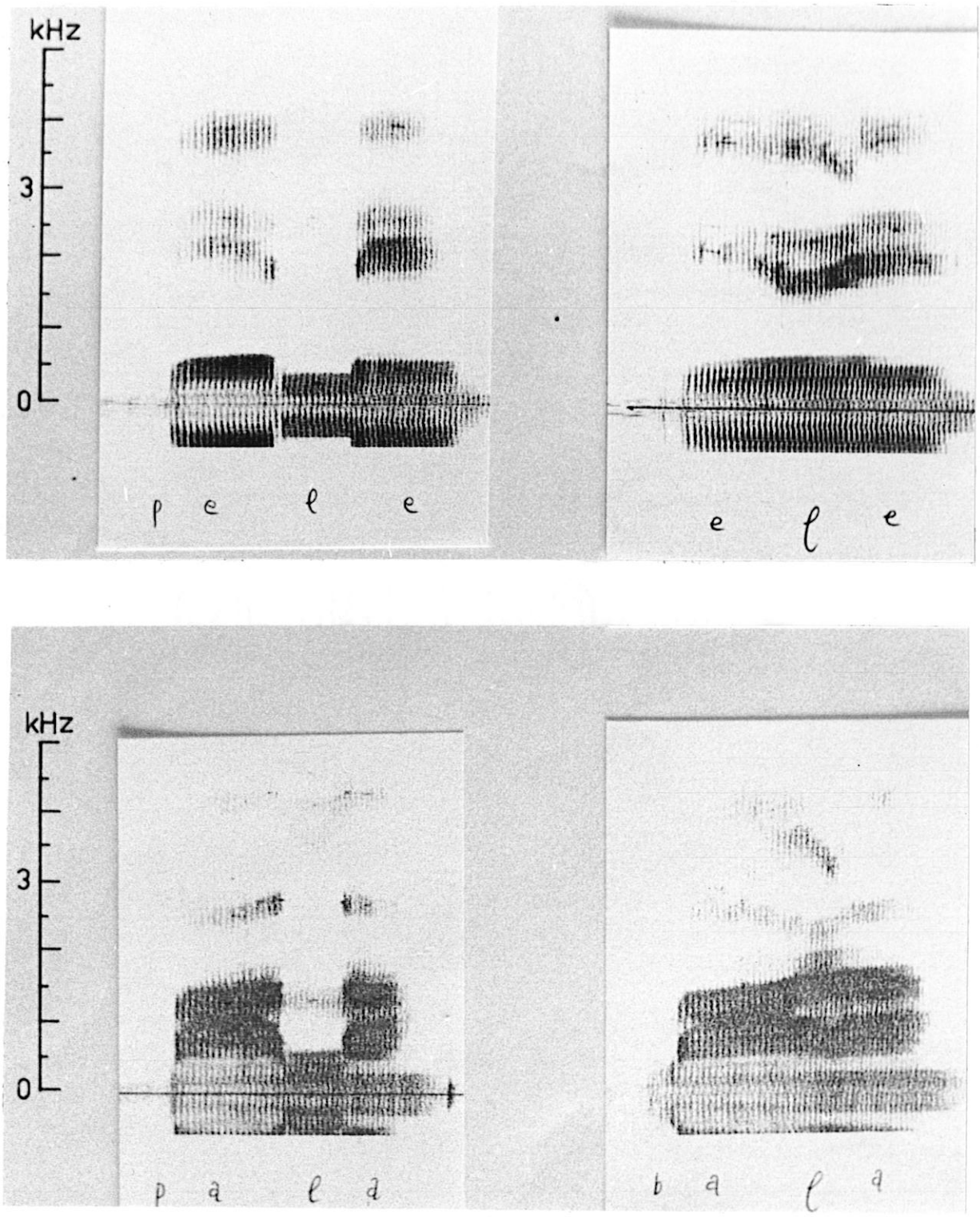


Figure IV.65. Spectrograms of pele, ele, pala, and bala (RT)

B. l and ḷ

The consonantal section.

The delimitation of retroflex ḷ from the preceding vowel is often problematic, as can be seen from the spectrograms Fig. IV.65 (the examples bala and eḷe). If, in the examples with retroflex ḷ, the beginning of ḷ were considered to start when the vowel transitions start, ḷ would have approximately the same length as l, and the preceding vowels would also be of the same length. However, if these spectrograms are compared to the spectrograms of retroflex ṛ (Fig. IV.62) and to spectrograms of retroflex stops, it seems more reasonable to consider the downward movement of formants 3 and 4 as belonging to the preceding vowel and to consider only the short period of closure of the flapped ḷ to belong to the consonant section proper. What happens is probably that the tongue moves relatively slowly up to the roof of the palate and then, after a very short touch, moves quickly down. The consonant proper has therefore been considered as starting where formants 3 and 4 have come down. Calculated in this way the closure time of dental l will be on the average 86 ms and that of retroflex ḷ only 27 ms, with no overlapping of the single cases. (l in ullu (185) is a gerinate and has beem left out in the averages.)

In contradistinction to ṛ and r, both l and ḷ show clear formant values during the consonantal section, as shown in the table below:

Table IV.1. Formants of l and l̇

Formants of dental l

Adjacent vowels	a	ə	u	o	i	e
No.	(8)	(1)	(1)	(1)	(2)	(2)
F_4	3669	3725	3500	3600	3850	3750
F_3	2697	?	2650	2650	2713?	2600
F_2	1281	1300	1350	1150	2563?	1600
F_1	319	350	250	275	275	275

Formants of retroflex l̇

Adjacent vowels						
No.	(2)	(1)	(1)	(1)	(2)	(1)
F_4	3330	3300	3100?	3550	3550	3425
F_3	2280	2500	?	1925	2425	2400
F_2	1400	1425	1100	1050	2000	1800
F_1	710	700	400	550	350	525

There are very clear differences in the formant frequencies between the two types of l: retroflex l̇ has a higher F_1, and in the environment of a and ə also a higher F_2, moreover, in all cases a lower F_3 and a lower F_4. The differences in F_1, F_3, and F_4 are found in all comparable

single pairs and are significant at the 1% level, and the difference in F_1 is consistent for ə and a.

Formant transitions of adjacent vowels.

The frequencies of start and end of the vowel transitions are shown in table 2 of Appendix D, and schematic drawings are given in Figs. IV.63-64.

The averages for the vowel a are based on 6 examples before l and l̇: 4 examples after l, and 2 after l̇, for the other vowels there are only 1-2 examples. As there were no consistent differences between the transitions after initial and medial consonants, nor before final and medial consonants, these examples have been combined into one average.

It appears from the tables and from the schematic drawings in Figs. IV.63-64 that differences in formant transitions between the dental l and the retroflex l̇ are found both in the preceding and in the following vowel, but most consistently in the preceding vowel. In a and ə F_1 ends at a higher frequency before l̇ than before l (and this is true of all 6 examples of a), but for the other vowels, and in vowels after l and l̇, there is no considtent difference.

F_2 is, on the whole, positive in a, ə, u, and o and negative in i and e, and there is a tendency to having a higher end point in al̇ and l̇ə than in la and lə; but it is not quite consistent, and for the other vowels one finds the opposite tendency.

F_3 and F_4 show much more consistent differences. Particularly the vowel before l̇ shows a more strongly negative transition than the vowel before l, and the end points of F_3 and F_4 are lower before l̇ than before

l in all cases (12 comparable pairs), the difference being significant at the 1% level. Similarly, F_3 and F_4 of the following vowel have a tendency to start at lower frequencies after ḷ than after l, but the difference is only found in 6 out of 8 comparable word pairs. The vowel a has sometimes an extra formant around 3000-3300 Hz, particularly before dental l. F_4 is also consistently lower in the steady state part of a vowel preceding retroflex ḷ than in one preceding dental l, whereas F_3 varies.

C. n and ṇ

The consonantal section.

Retroflex ṇ is a flapped consonant like ḷ and ṛ, and the delimitation is not too easy, although not as difficult as in the case of ḷ. The transitions have been considered to belong to the vowels, and ṇ is thus of very brief duration (see the spectrograms Fig. IV.68). The average duration of n is 88 ms, and that of ṇ 31 ms and there is no overlapping (n in unna has been left out of the average, because it is a geminate (170 ms)).

The formants of nasal consonants are not easy to measure. They are rather irregular, and some may be too weak to appear on spectrograms. Particularly the higher formants are dubious, and the averages for ṇ before i are rather problematic.

Nevertheless, some consistent differences appear from the tables:

Table IV.2. Fromants of n and n̤.

Formants of dental n

Adjacent vowels	a	ə	u	o	i	e
No.	(6)	(1)	(1)	(1)	(3)	(1)
F_4	4275 (3075)	4400	3700 (2900)		3775	
F_3	2563	2415	2600	2525	2680	2575
F_2	1450	1325	1425	1200		
F_1	313	275	300	300	300	300

Formants of retroflex n̤

Adjacent vowels	a	ə	u	o	i	e
No.	(6)	(1)	(1)	(1)	(3)	(1)
F_4	3400			3450	3870	
F_x	2625	2800	2800	2900	2867?	2800
F_3	2125	2300	1850	1900	2400	?
F_2	1408	1450	1225	1100	2063?	1900
F_1	250	250	300	225	350	300

There are no consistent differences between F_1 or F_2 of dental and retroflex nasals. F_3 is, however, consistently lower in n̤ than in n. This is

true of 12 comparable pairs, and the difference is significant at the 1% level.

Moreover, n̤ has in all positions a formant around 2800 Hz.

Formant transitions in adjacent vowels.

The frequencies of start and end of the transitions are given in table 3 of Appendix D, and schematic drawings of the transitions in Figs. IV.66-67. There are no consistent differences between vowel transitions in connection with dental and retroflex consonants in F_1 and F_2, but there are clear differences in F_3 and F_4. Vowels before retroflex n̤ have a more pornounced negative transition of F_3 and F_4 than vowels before dental consonants, and in most cases there is also a difference in the F_3 transition after the consonant. F_4 has a lower end point of the transition before retroflex n̤ in all 12 comparable pairs, and F_3 in all of 10 comparable pairs. In the position after the consonants the same tendency is found, but not consistently (6 out of 8 comparable pairs). F_4 in the steady state part of a vowel preceding retroflex n̤ is also consistently lower than in one preceding dental n, whereas F_3 is variable.

A further difference between RD's dental and retroflex nasals is that the retroflex consonants tend to nasalize the preceding vowel to a higher degree, cf. Fig. IV.68. The vowel before n̤ has a higher and weaker F_1 and a stronger subformant than the vowel before n.

The common features for retroflex r̤, n̤, and l̤ are thus a lowering of the third and fourth formants of the preceding vowel, and the lowering is also seen for the F_3 and F_4 of l̤ and n̤.

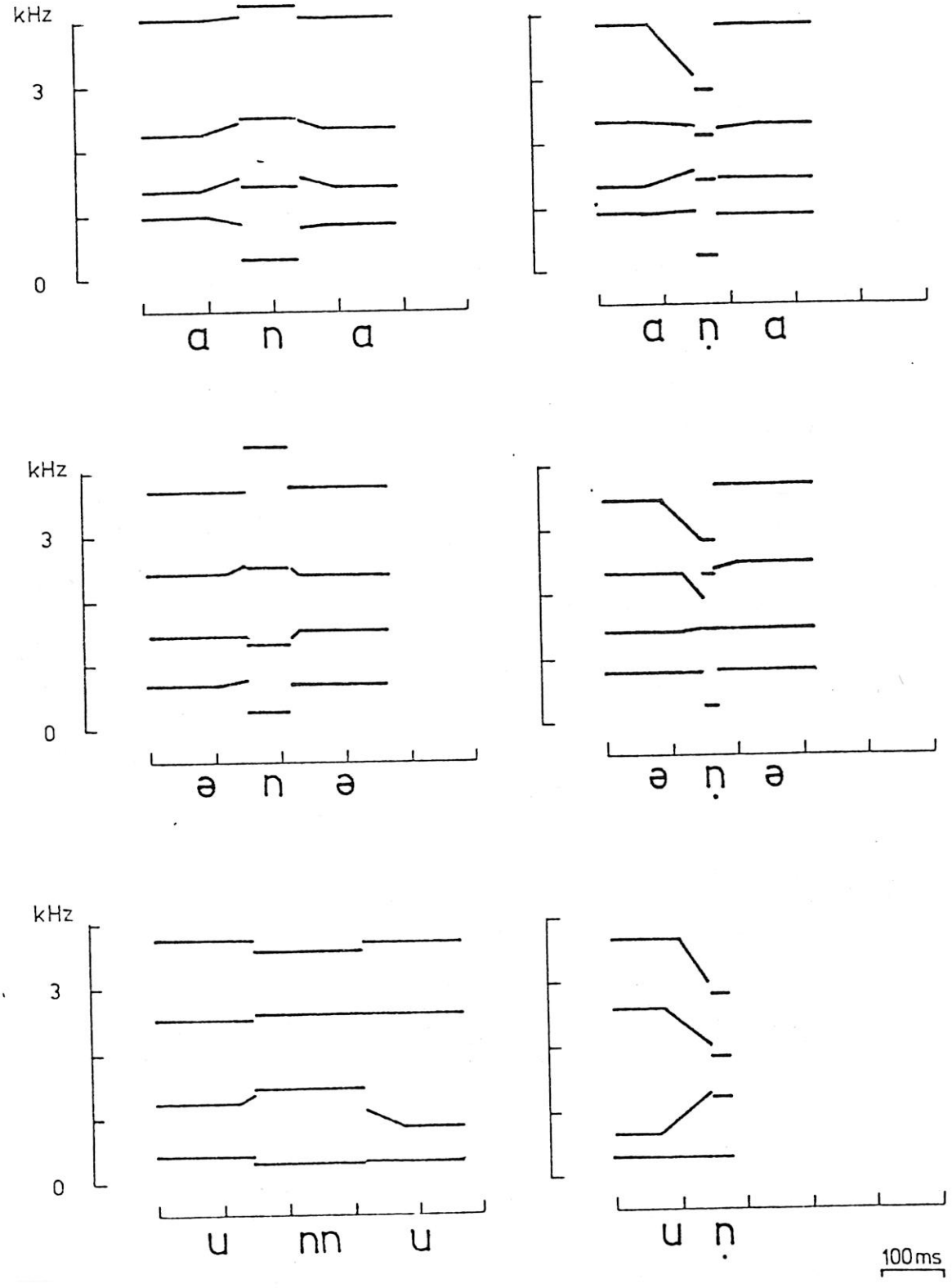


Fig. IV.66. Schematic drawings of formant transitions.

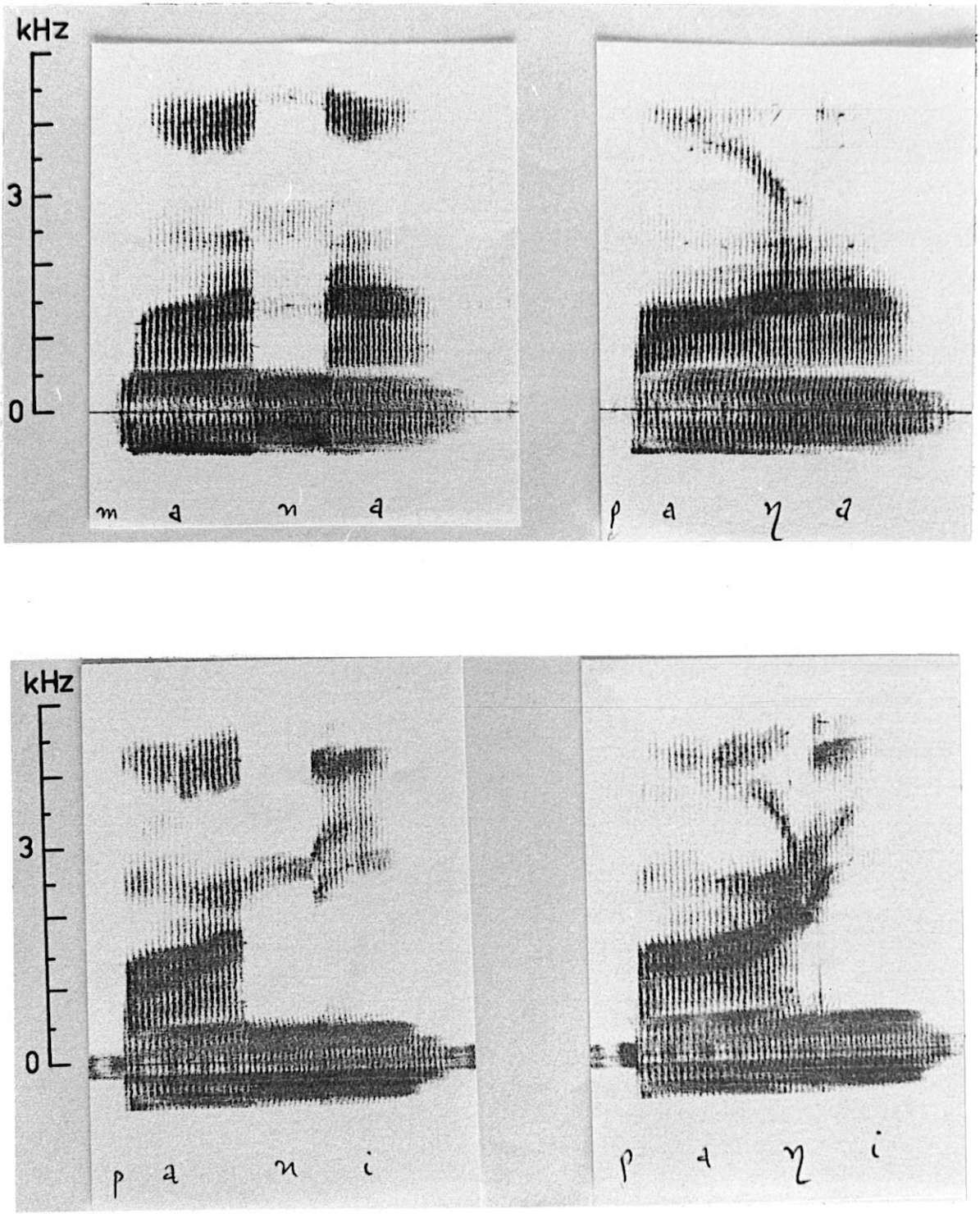


Figure IV.68. Spectrograms of mana, pana, pani, and pani.

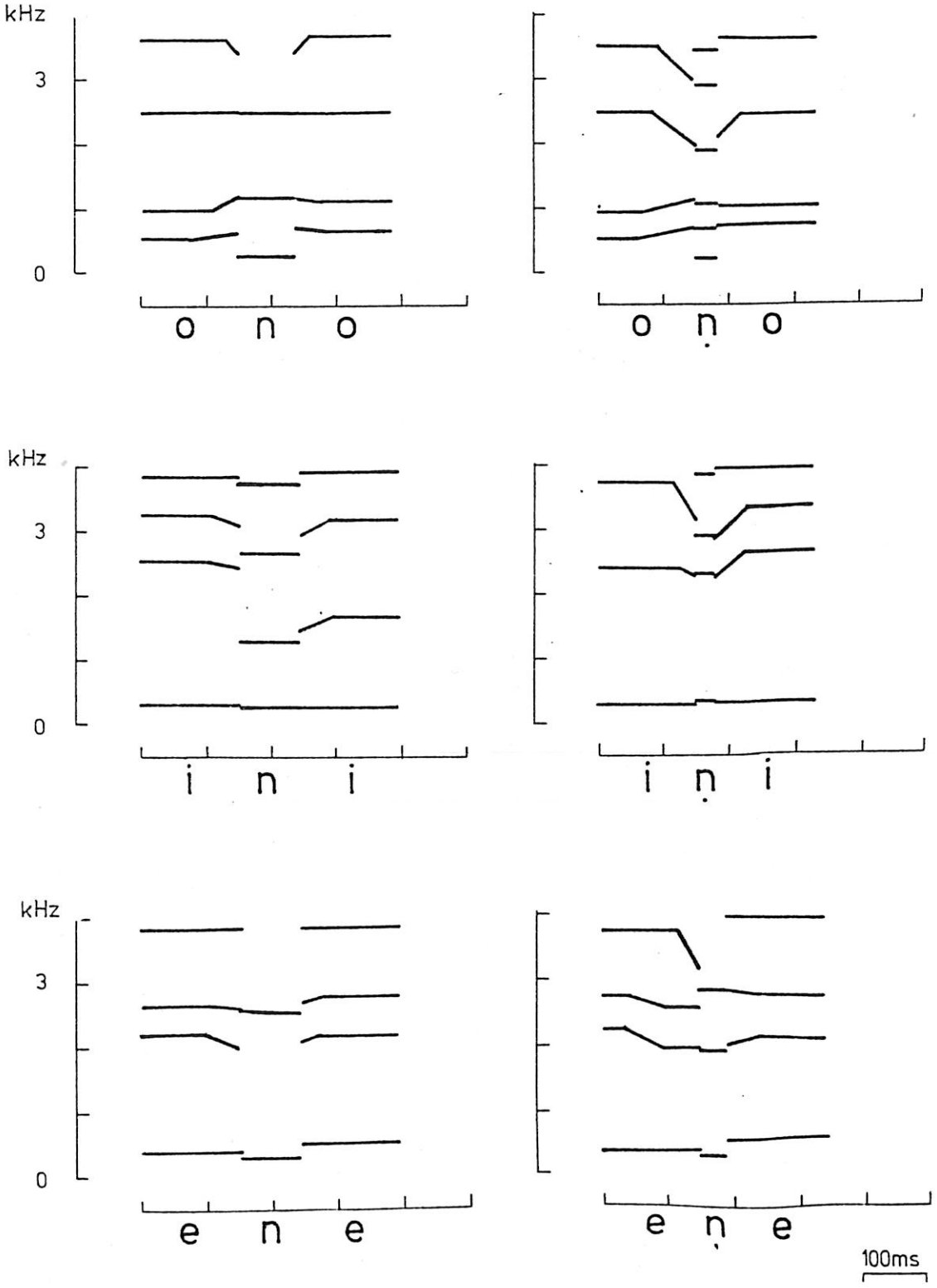


Figure IV.67. Schematic drawings of formant transitions.

D. RT's retroflex liquids and nasals.

The spectrograms of RT show, on the whole, the same differences between dental and retroflex consonants as those found in RD's spectrograms. The lowering of F_3 before retroflex consonants is particularly clear. He also has the tendency to higher frequency of F_2 before r. As for F_4, he has some cases of clearly negative transition before retroflex consonants, but the fall is generally slower than in RD's curves and very often missing. Two pairs of spectrograms reproduced in Fig. IV.69 from RD and RT show this difference.

IV.2.52. Stops.

Both dental and retroflex stops are found in all positions of the word: initially, medially, and finally. Spectrograms have been taken of the unaspirated voiced and voiceless stops in all three positions in the environment a-a, and initially and medially in connection with other vowels. As was the case with the liquids, consonants in word-initial and syllable-initial position have been combined in a common average, and the same is true of word-final and syllable-final position.

Temporal relations.

In accordance with what has been found in other languages there is a clear difference in closure duration between RD's medial t-ṭ and d-ḍ. There are 8 pairs of retroflex consonants and no exceptions, which gives significance at the 1% level.

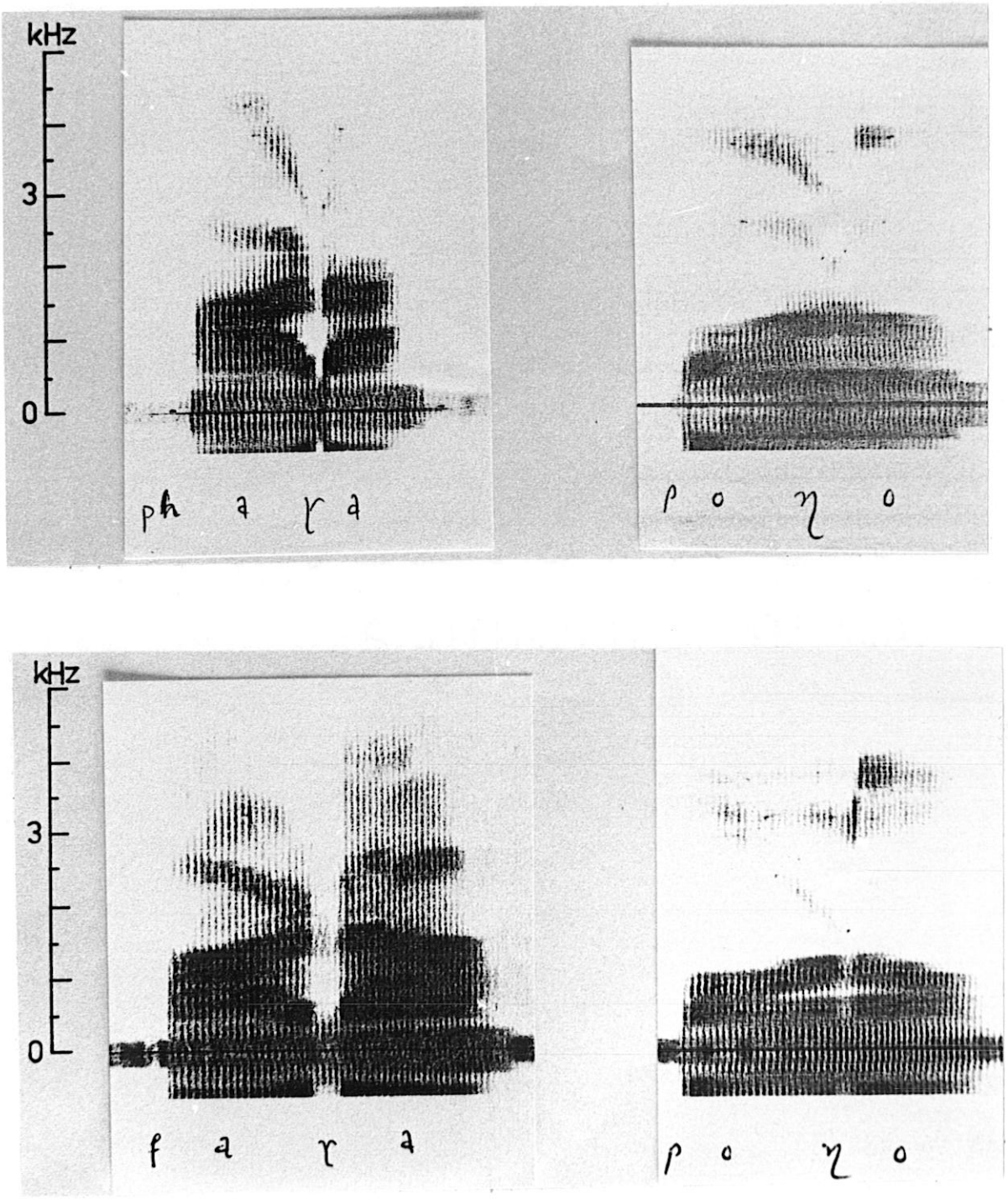


Figure IV.69. Spectrograms of Phara, pono (RD), and fara, pono (RT).

There is, moreover, a tendency for the retroflex consonants to have a slightly shorter closure than the dental consonants, but this difference is not consistent. The general averages are:

t 124 ms, ṭ 114 ms, d 83 ms, ḍ 71 ms.

RT has quite similar relations, namely:

t 106 ms, ṭ 103 ms, d 68 ms, ḍ 51 ms.

But he has only 3 examples where ḍ is pronounced as a stop. Normally he pronounces it as a flap.

More important is the differnece in distance between burst and vowel start, found in RD's spectrograms. This distance has sometimes been called "open interval" (e.g. by Fant and by Eli Fischer-Jørgensen 1954), but is now commonly called "voice onset time", abbreviated VOT, a term which has been introduced by Lisker and Abramson (1964).

In RD's spectrograms the VOT value is smaller for retroflex consonants than for dental consonants. For the voiced stops the VOT is in any case very short and sometimes difficult to measure, but there is at least a tendency for ḍ to have a few ms shorter VOT than d. For the voiceless stops the difference is quite clear. The averages (in ms) are:

	a	ə	u	o	i	e
t	15	15	16	15	24	20
ṭ	9	9	13	10	10	9

There are 27 examples of t and 25 of ṭ, and of 24 comparable pairs the dental consonant has a longer VOT in 21. This is significant at the 1% level.

However, the other informant (RT) has no such difference between dental and retroflex stops. The VOT of his dental stops is on the average 15 ms, and that of his retroflex stops 16 ms.

Burst frequency.

The burst frequency has been analysed by the linear prediction method, mentioned in IV.2.4. When the point for analysis is chosen at point zero, so that the time window has its peak at the start of the burst, the spectrum of the bursts of voiceless stops will, in most cases, be based on the burst alone, except for some cases of retroflex stops where there may be a slight influence from the vowel start.

Figs. IV.70-75 show such spectra of the bursts of RD. Dental stops are shown at the top, and retroflex stops at the bottom of each figure. In most of the drawings 2-3 examples of stops at point zero before the same vowel have been superimposed in order to show the variation. The differences between the two types are not very consistent although some general trends can be seen. Before a, u, o, and ə there is more energy at higher frequencies in the dental stops. They generally preserve their intensity up to at least 4000 Hz, whereas the intensity gradually falls off at higher frequencies in the retroflex stops. Before i and e, however, no such difference can be seen, and before a the difference is not consistent. Figs. IV.76-79 show similar spectra from RT. There is generally only one example before each vowel, and dental and retroflex stop bursts have therefore been shown in the same diagram, the retroflex stops being indicated by a dashed line. Only examples before a, ə, o, i are given (as there was no pair before u, and before e it was

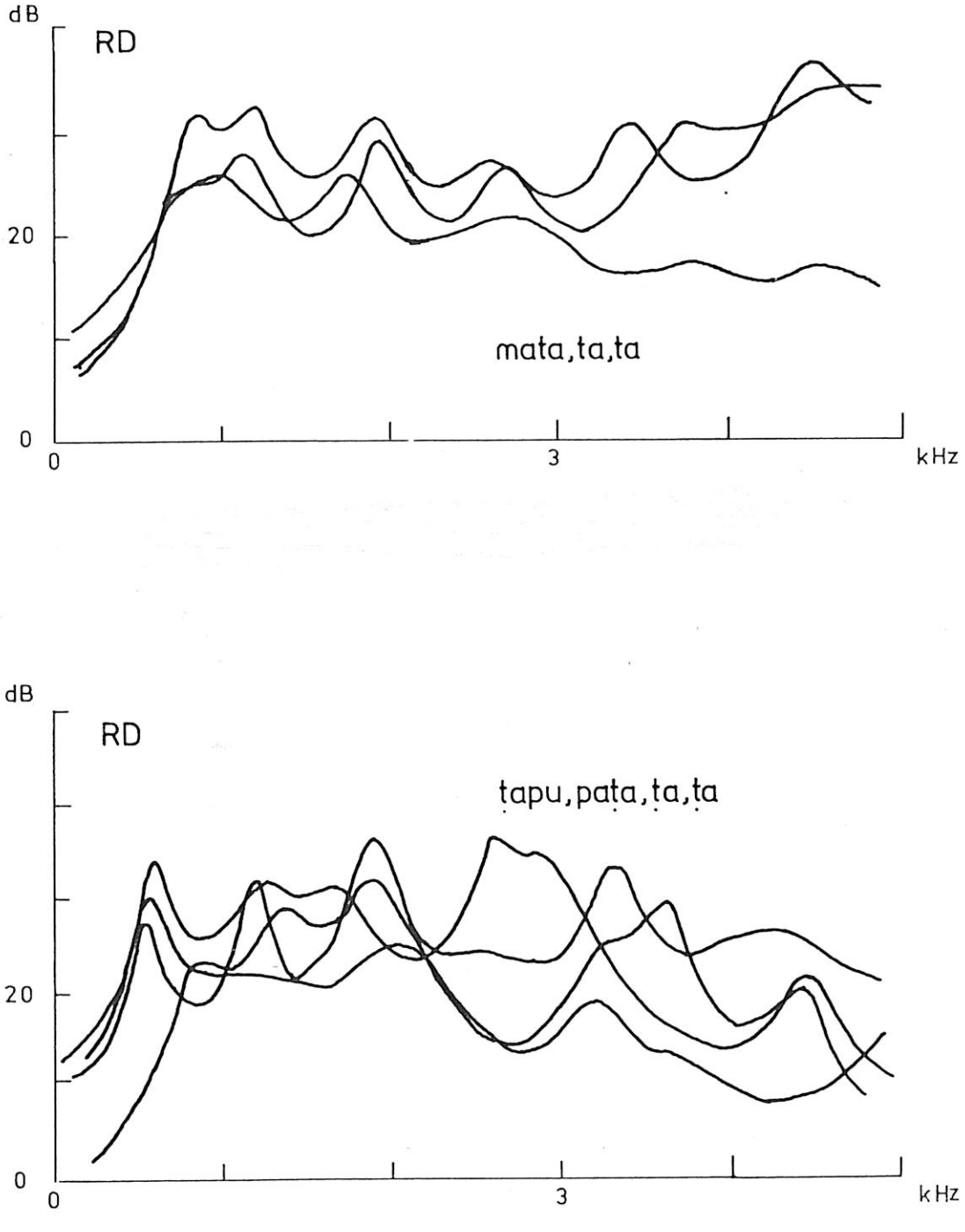


Figure IV.70. Spectra of bursts (RD).

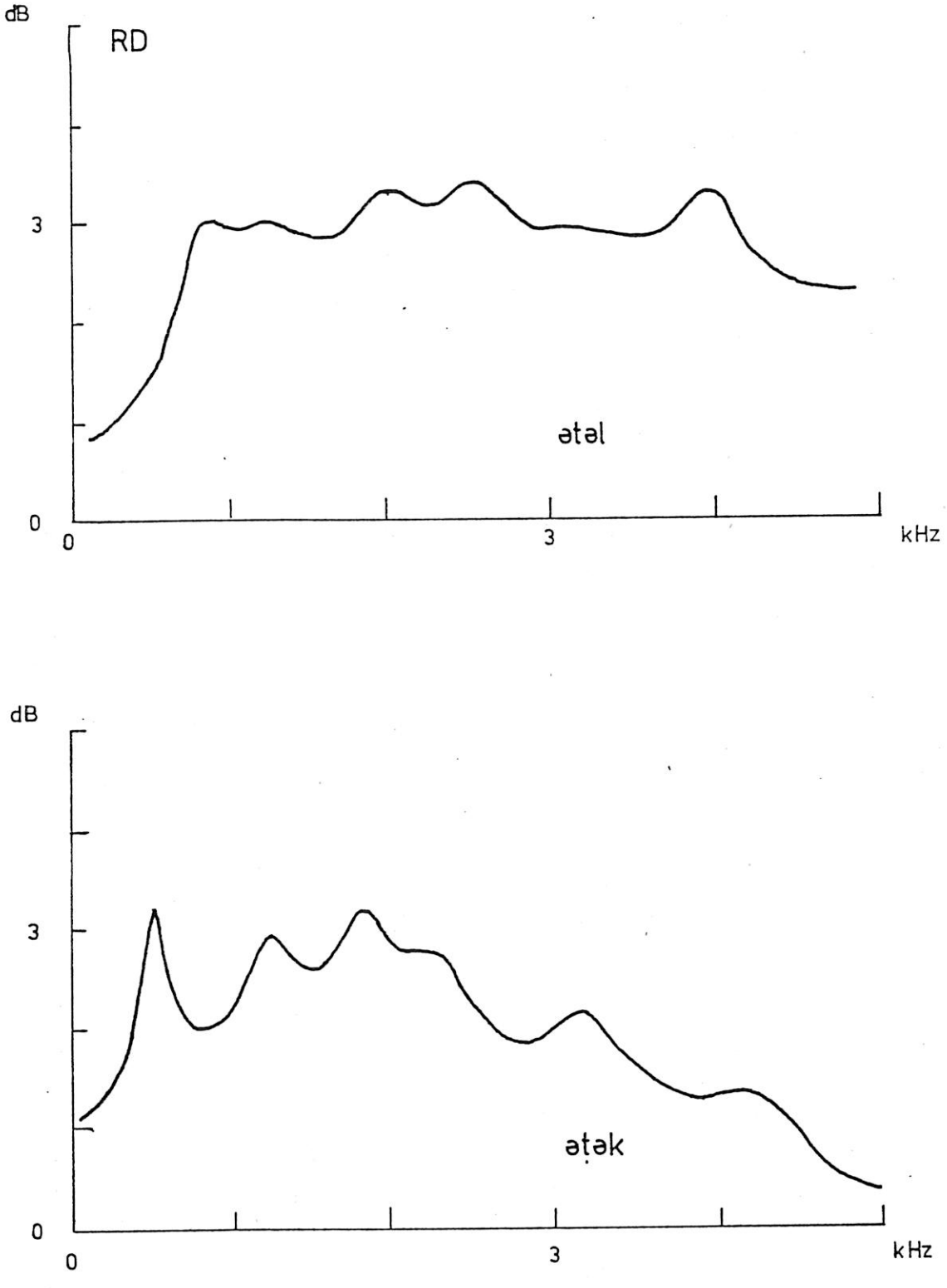


Figure IV.71. Spectra of bursts (RD).

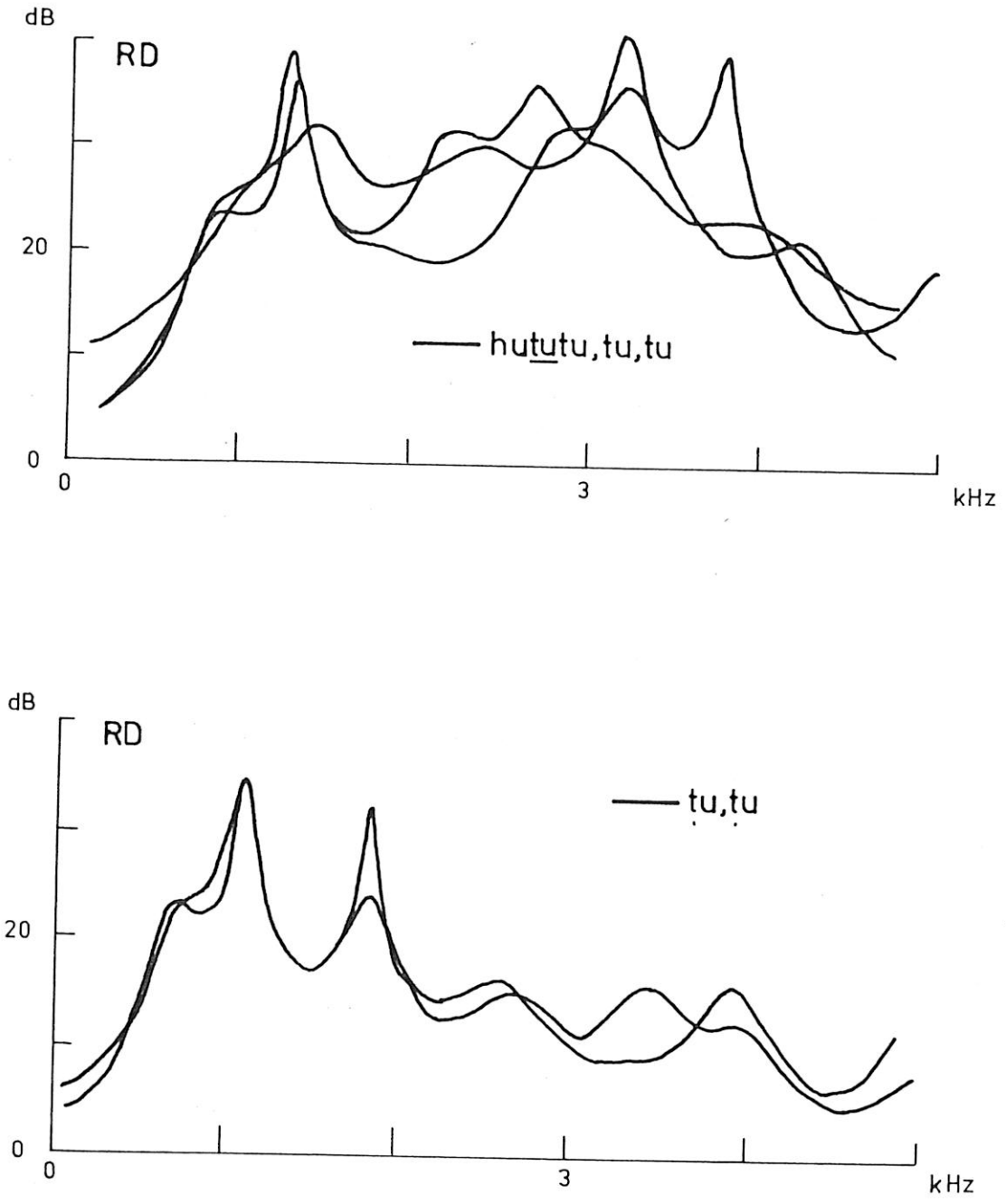


Figure IV.72. Spectra of bursts (RD).

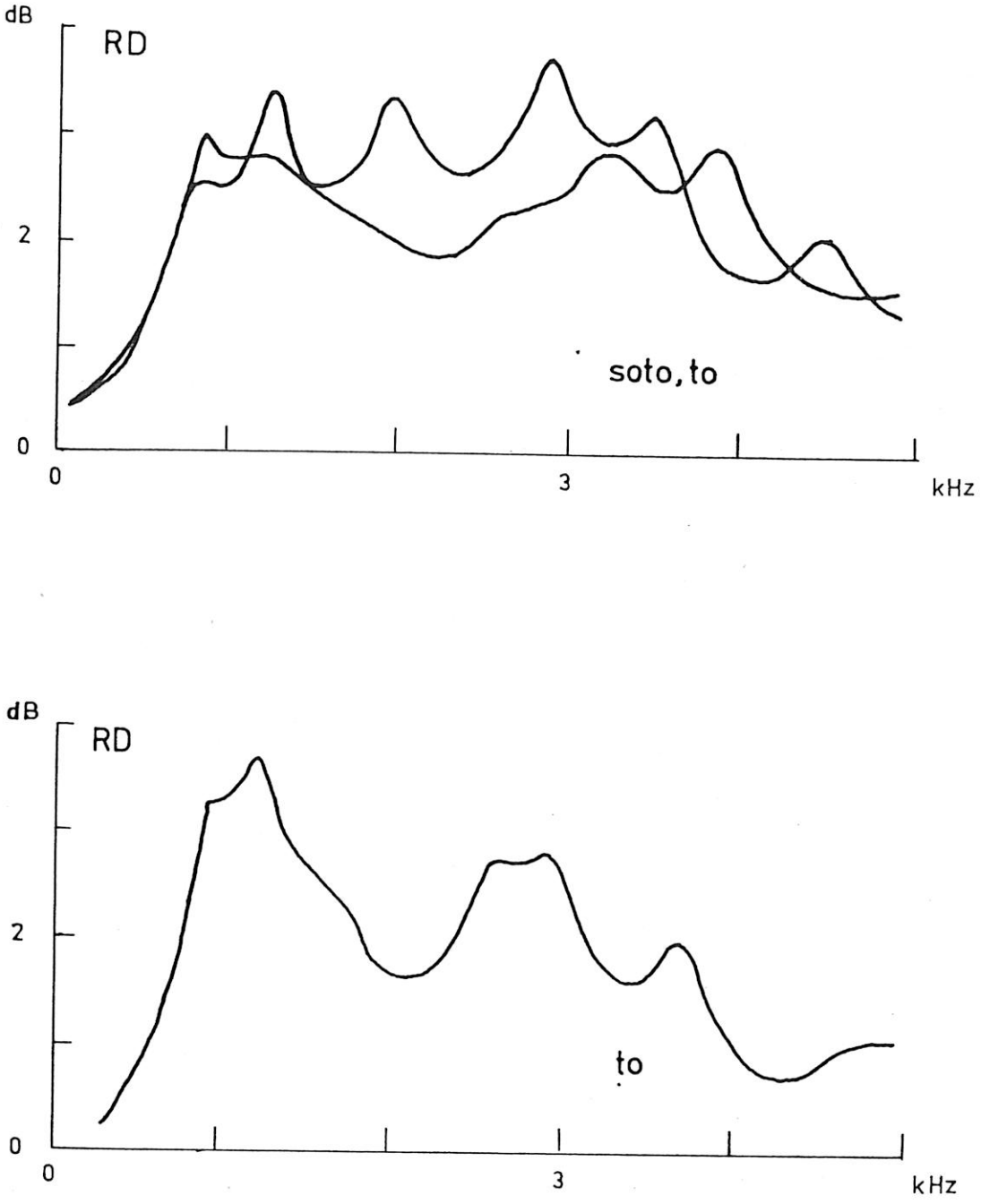


Figure IV.73. Spectra of bursts (RD).

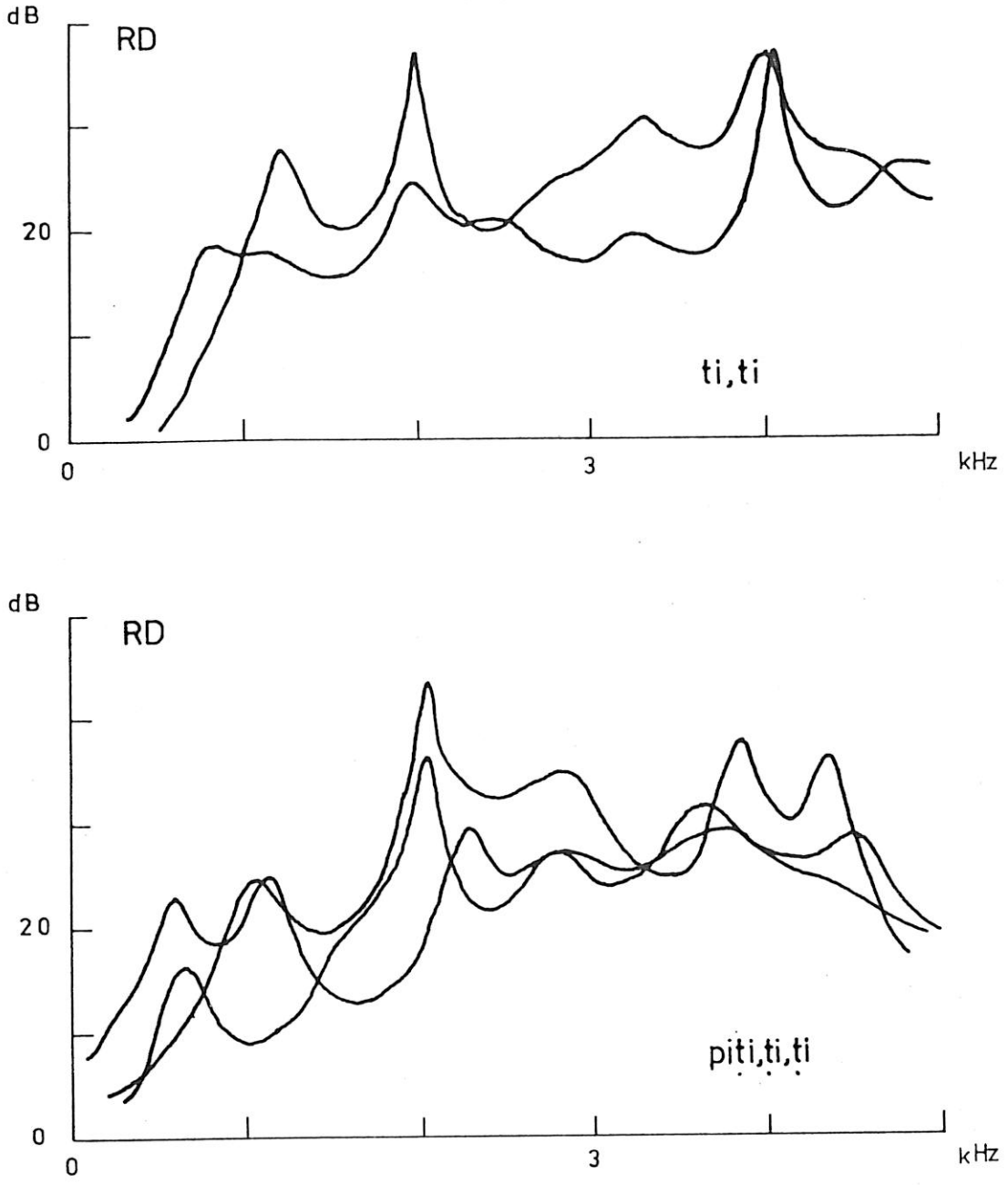


Figure IV.74. Spectra of bursts (RD).

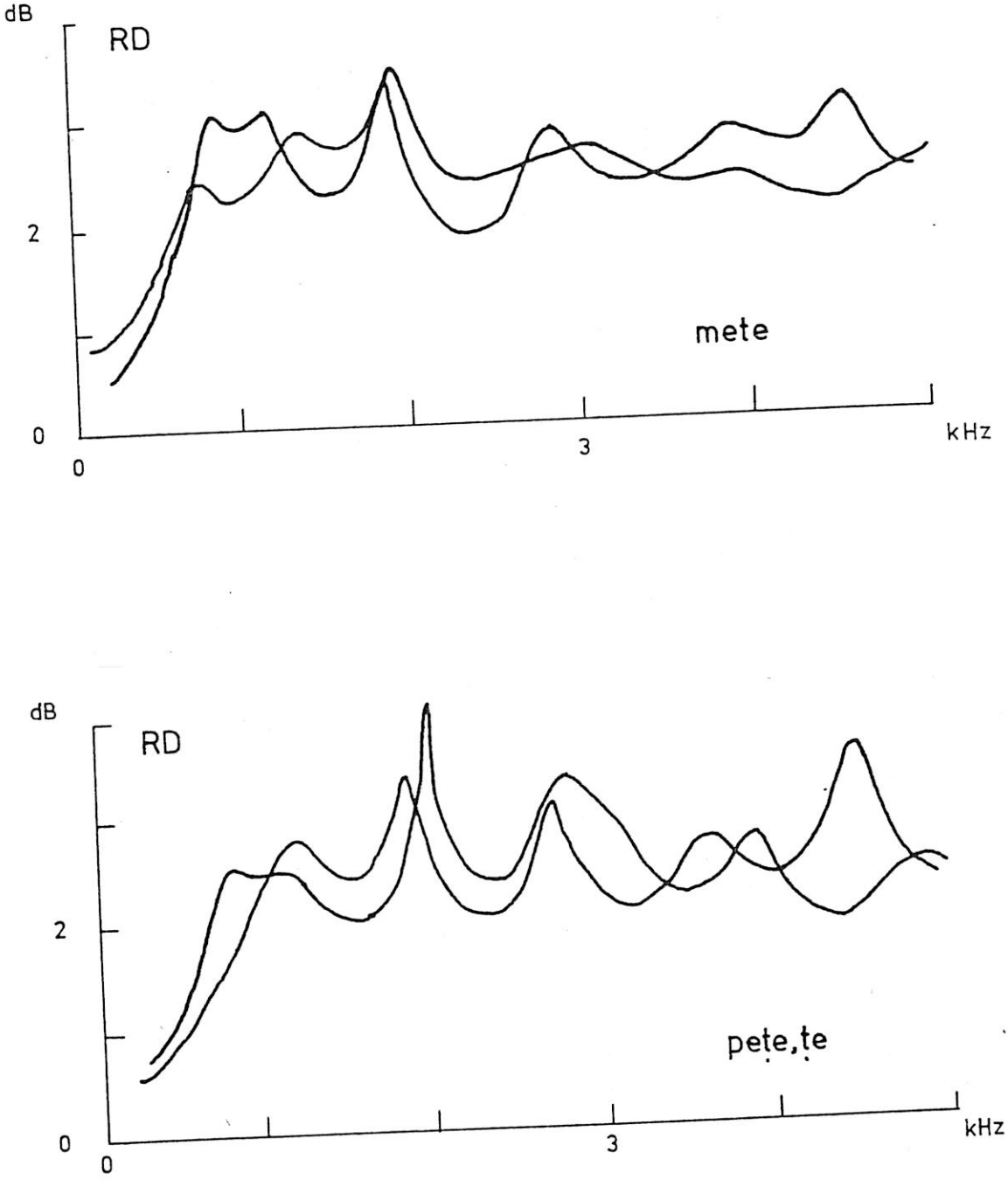


Figure IV.75. Spectra of bursts (RD).

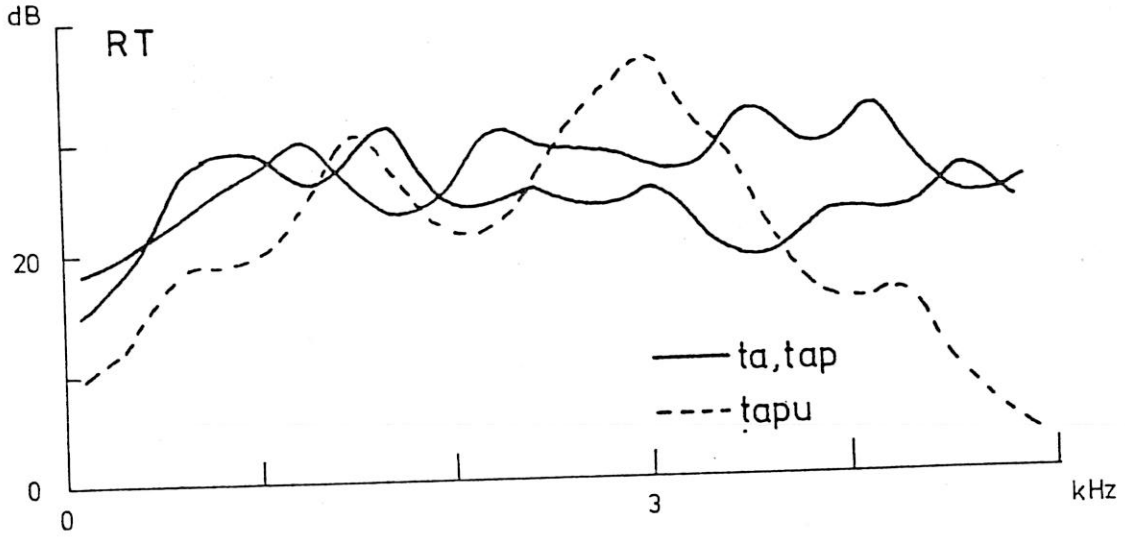


Figure IV.76. Spectra of bursts (RT).

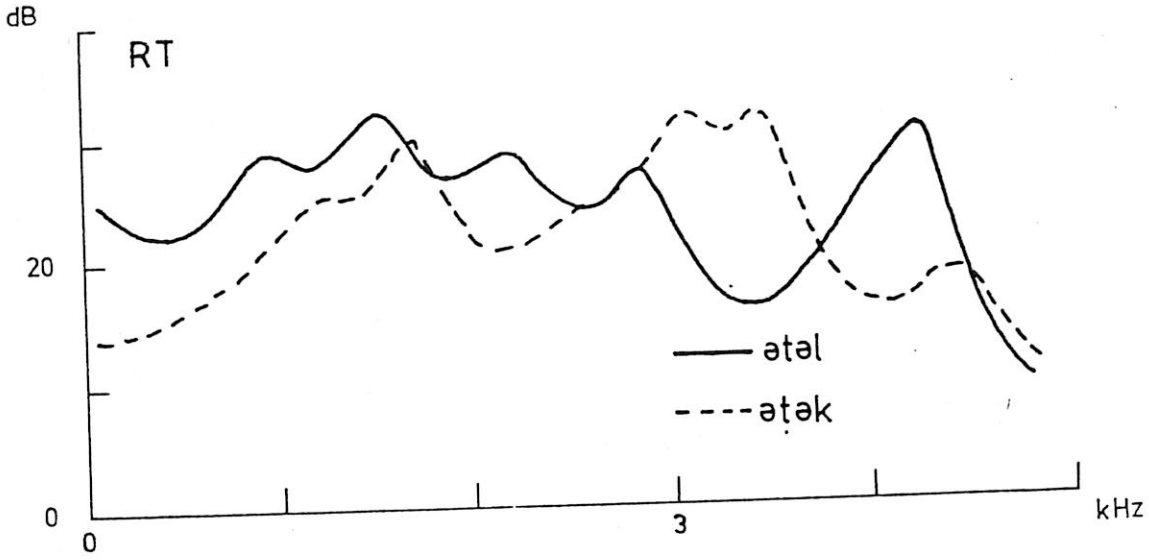


Figure IV.77. Spectra of bursts (RT).

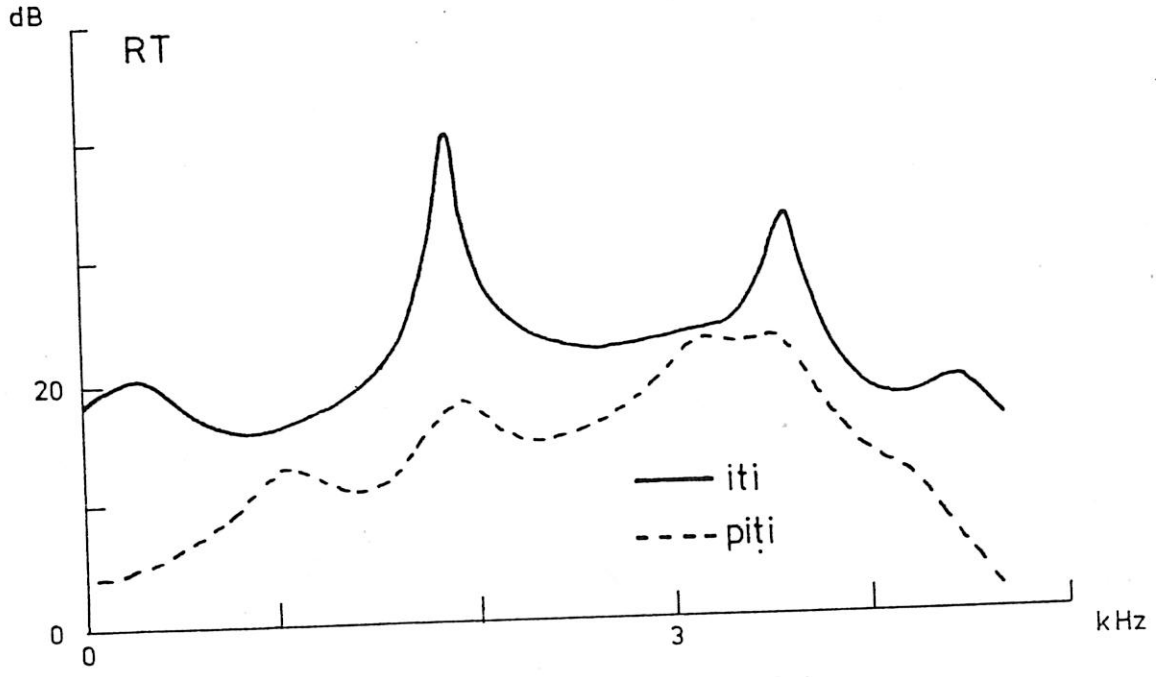


Figure IV.78. Spectra of bursts (RT)

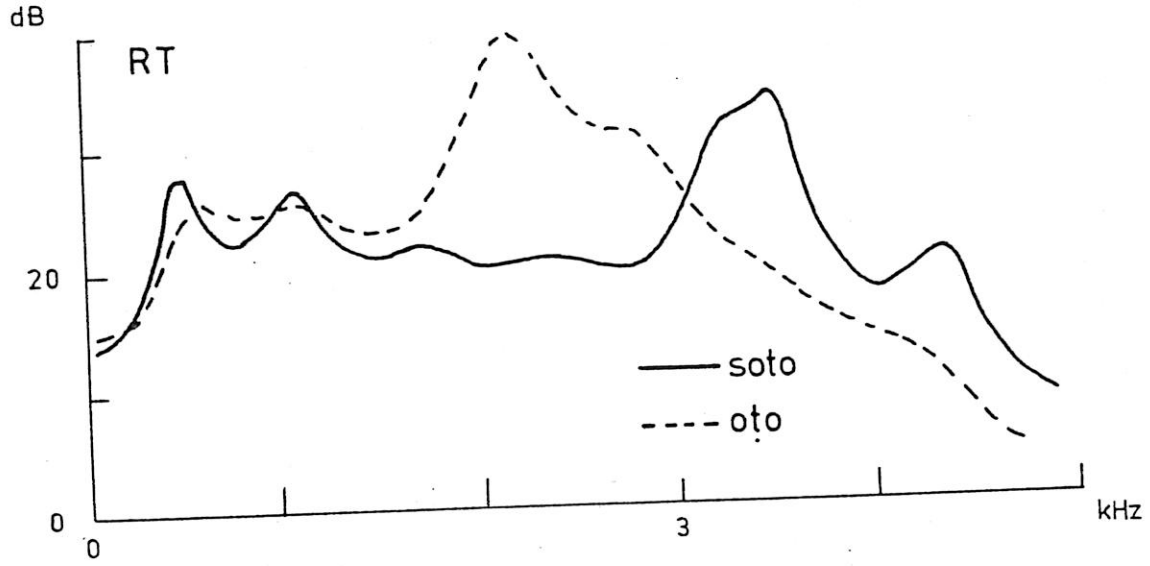


Figure IV.79. Spectra of bursts (RT).

not possible to distinguish the zero-curves from the other curves of the original picture).

RT has a more consistent difference: the bursts of the retroflex consonants seem to have a rather broad peak around 3000 Hz, somewhat higher for i and lower for u. RD has such a broad peak in one example before a and one before ə, but not in other cases. But RD's tendency to having more energy at higher frequencies in bursts of dental stops is confirmed by inspection of the spectrograms, not only in the spectrograms of the same examples, but also in spectrograms of other words. For stops before o and u the spectrograms show the same as the linear prediction spectra, because the whole difference lies below 5000 Hz, but for the other vowels the spectrograms show a difference at higher frequencies. It is rare that there is anything to be seen above 4-5000 Hz in retroflex stop bursts before a and ə, but dental stops show energy around 5-6500 Hz and sometimes higher (see Fig. IV.80, showing the differences before ə). As for stops before the front vowels e and i, both may show some energy above 5000 Hz, but the retroflex stops have a concentration of energy from 2500-4500 Hz, whereas the dental stops have more energy at higher frequencies. This is very evident for e (Fig. IV.81). Before i both have frequency noise but ti has less energy at the frequencies at which ti shows concentration of energy. These differences are rather consistent.

In RT's spectrograms the distinction is less clear; he often has some energy above 5000 Hz in the bursts in all cases; there is, however, some difference (see Fig. IV.83).

In Figs. IV.84-86 spectra of velar bursts are shown for comparison. g and k have been combined in the same graph, since g has a longer

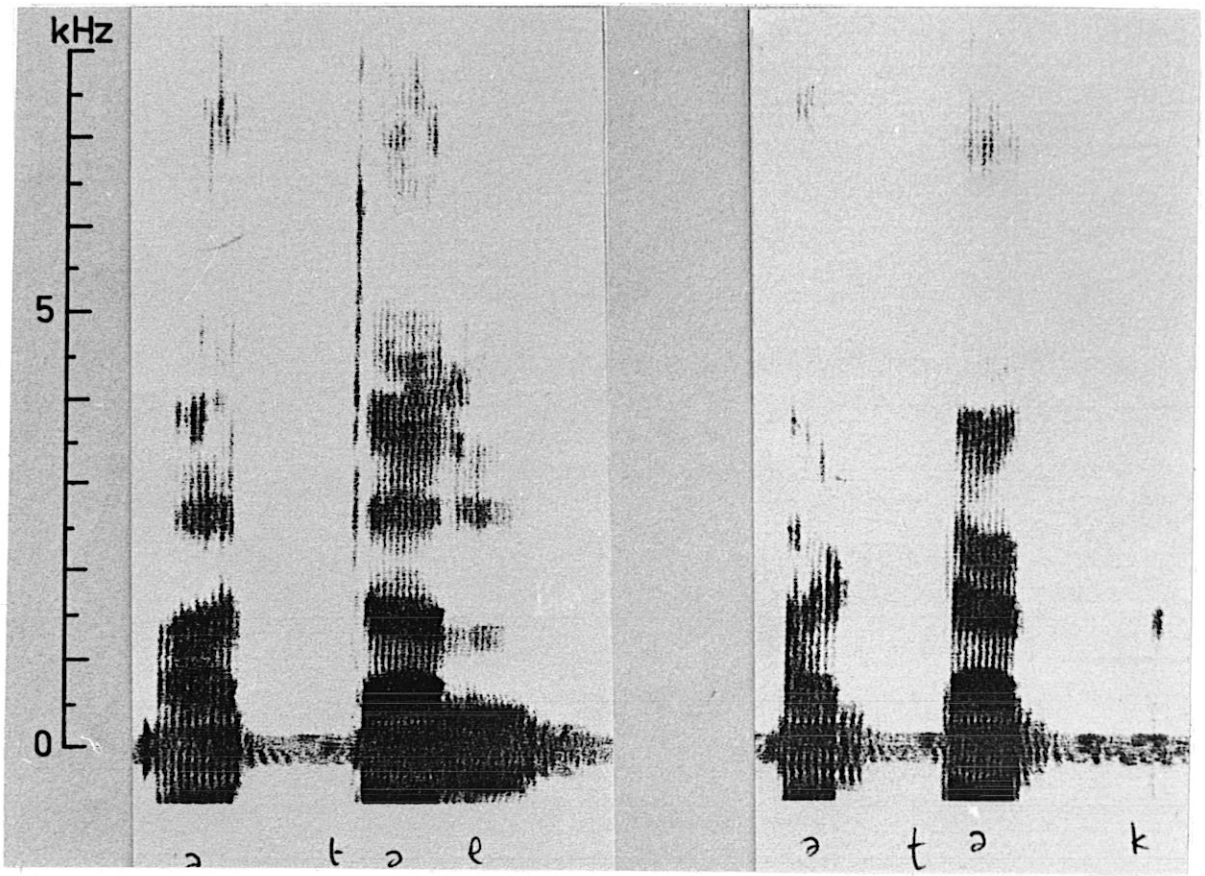


Figure IV.80. Spectrograms of words with t and t̤ before ə (RD).

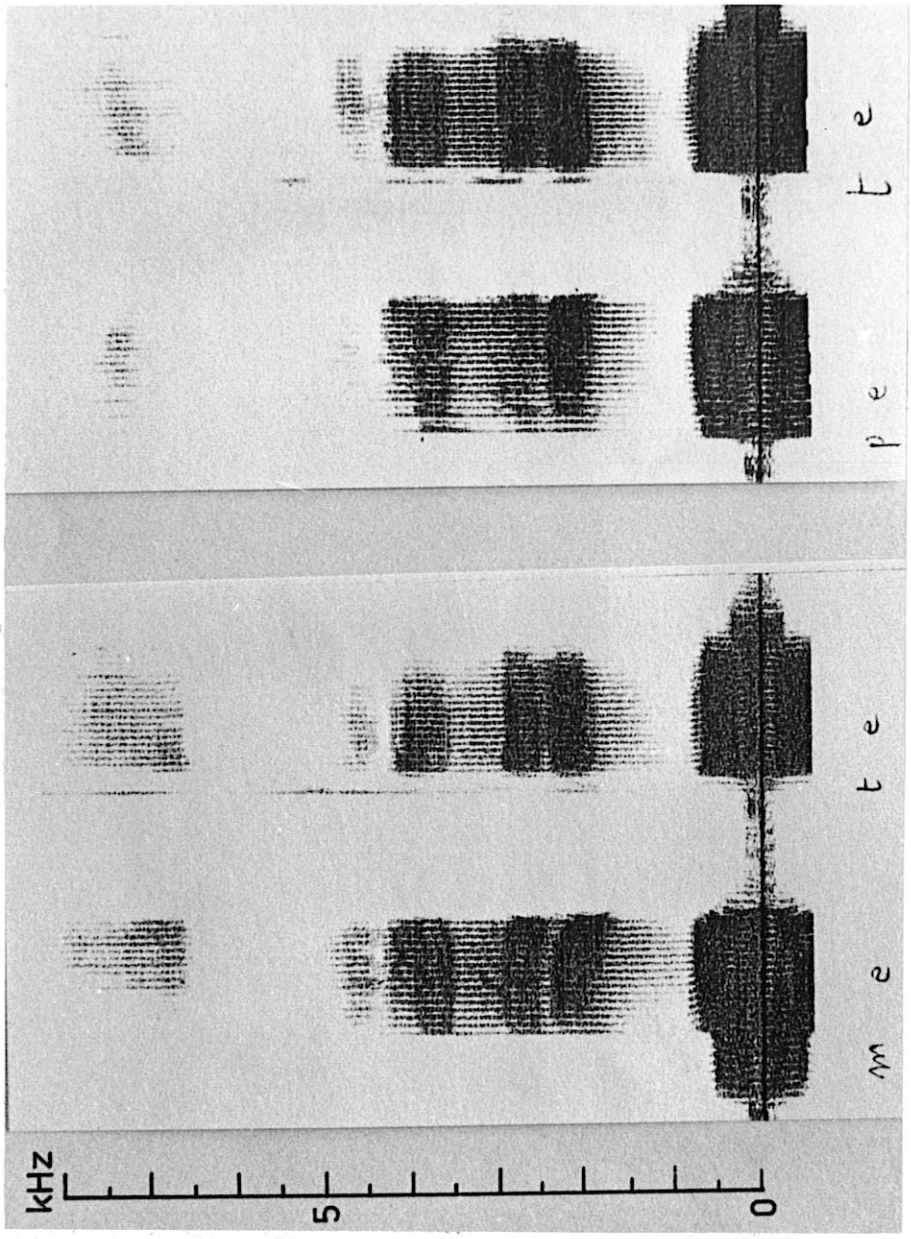


Figure IV.81. Spectrograms of words with t and t before e (RD).

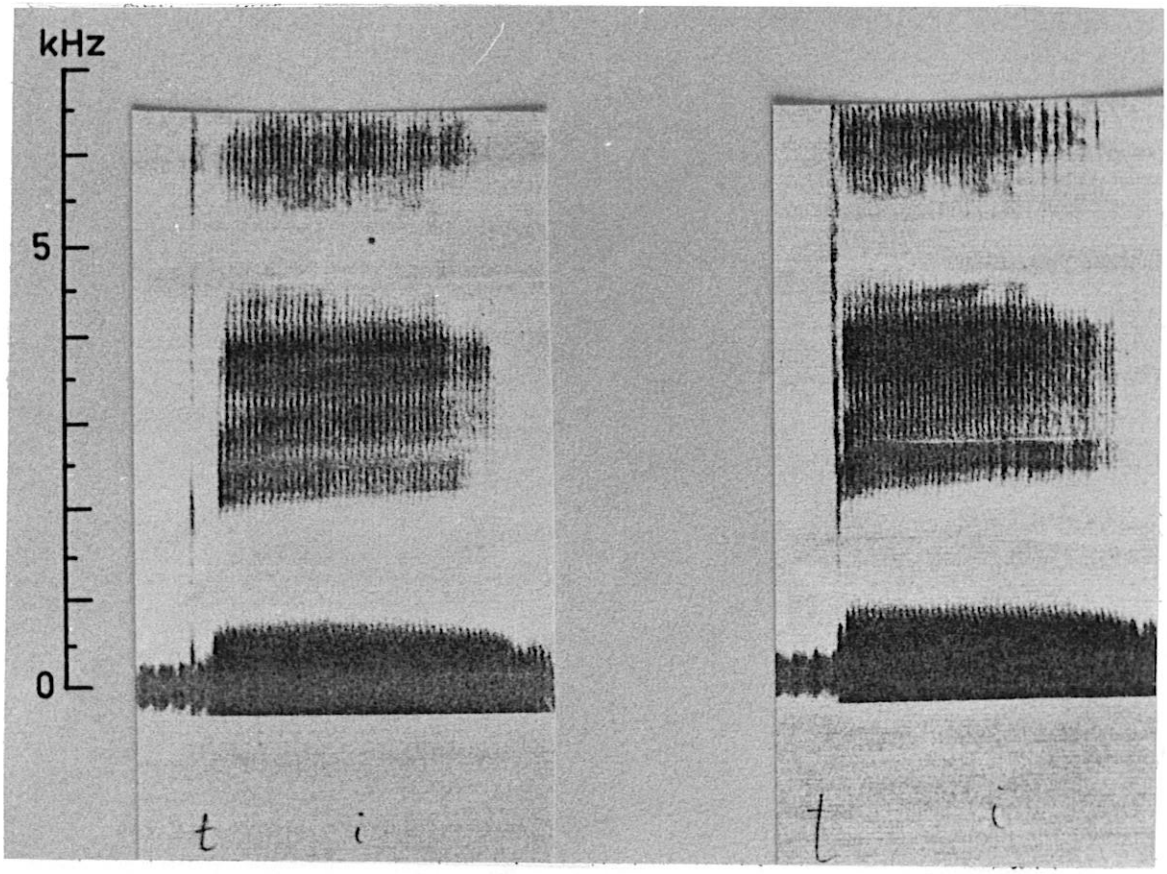


Figure IV.82. Spectrograms of words with t and t̤ before i (RD).

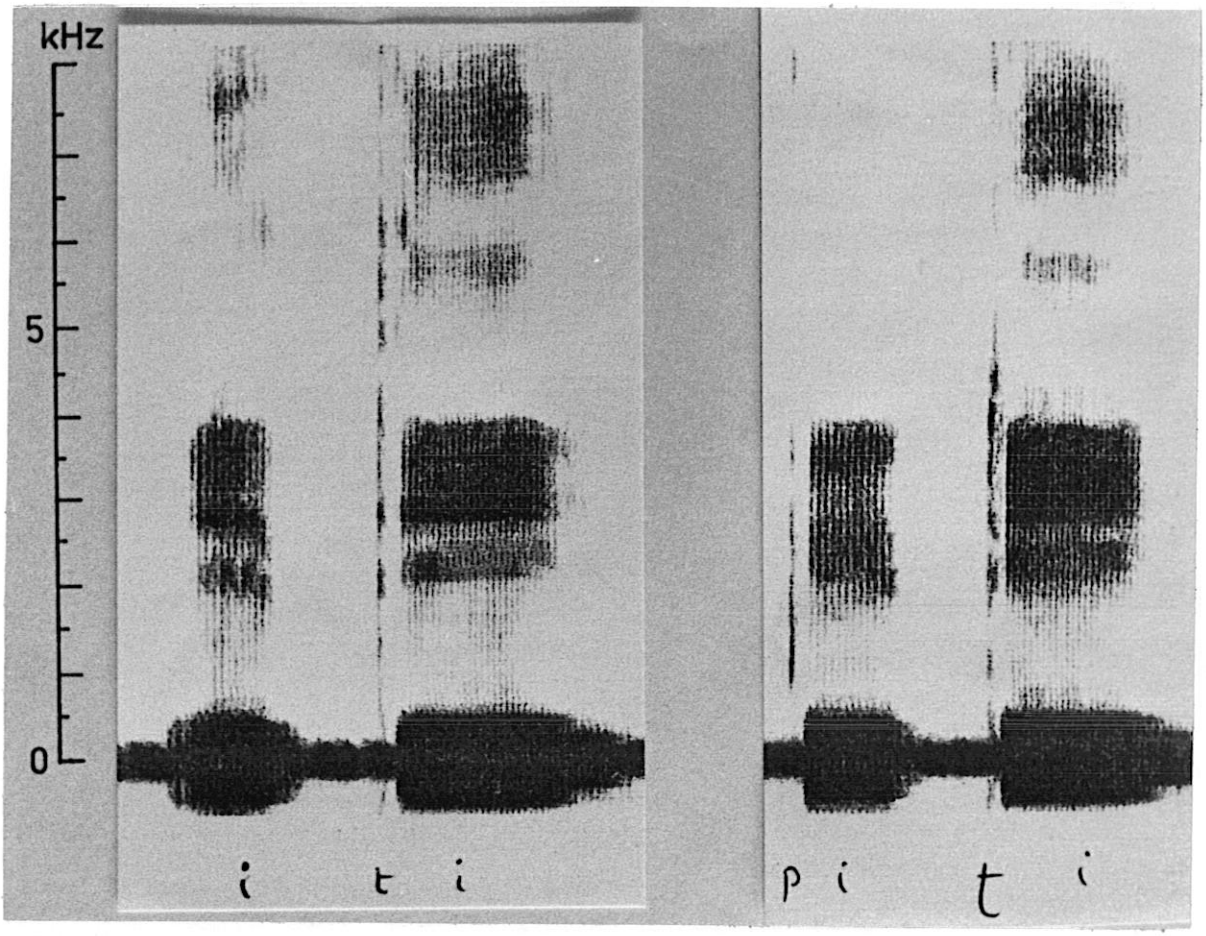


Figure IV.83. Spectrograms of words with t and t̤ before i (RT).

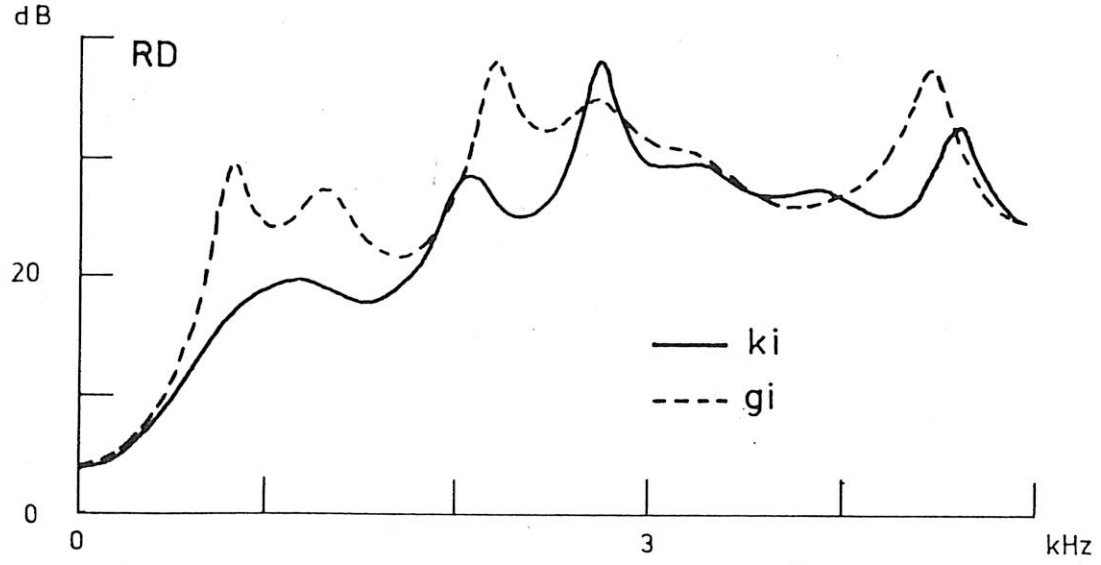


Figure IV.84. Burst spectra of velars before i. (RD)

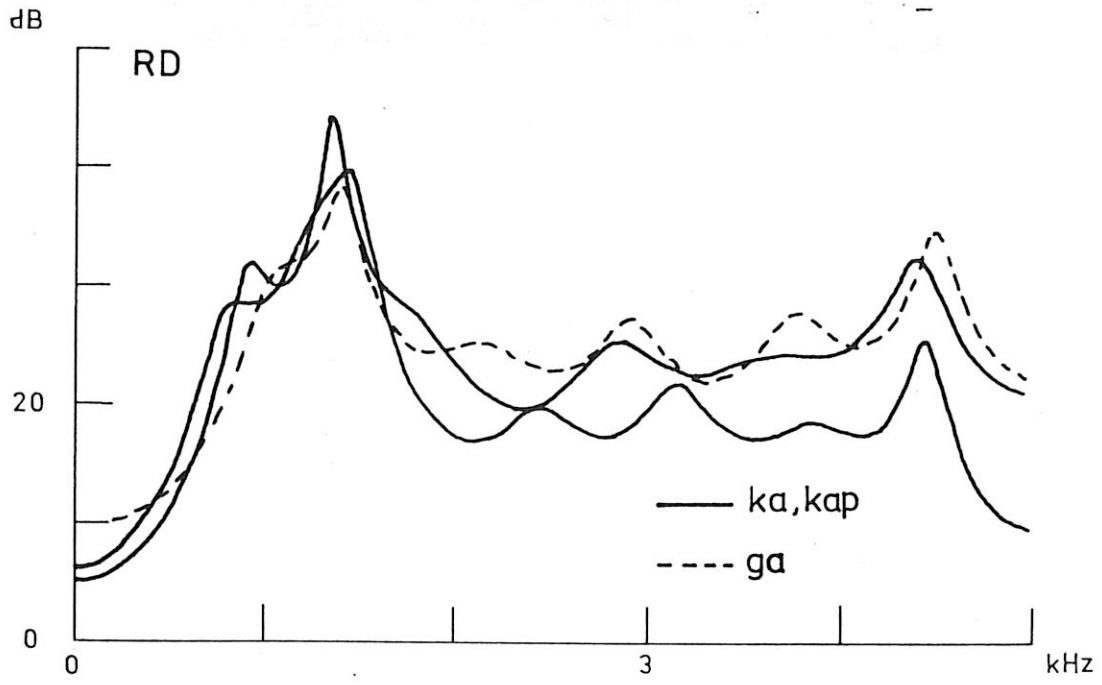


Figure IV.85. Burst spectra of velars before a. (RD)

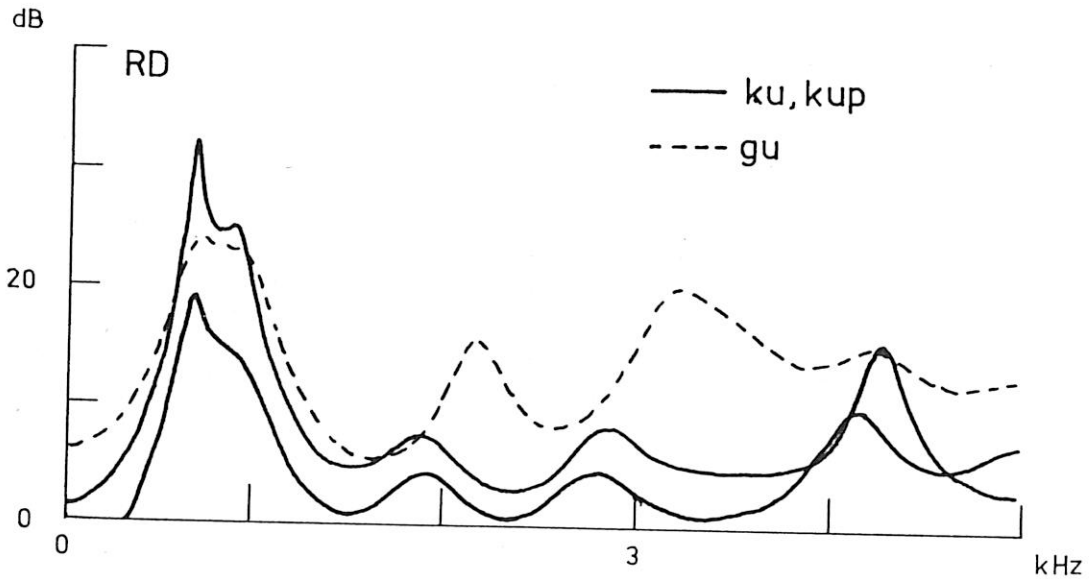


Figure IV.86. Burst spectra of velars before u. (RD)

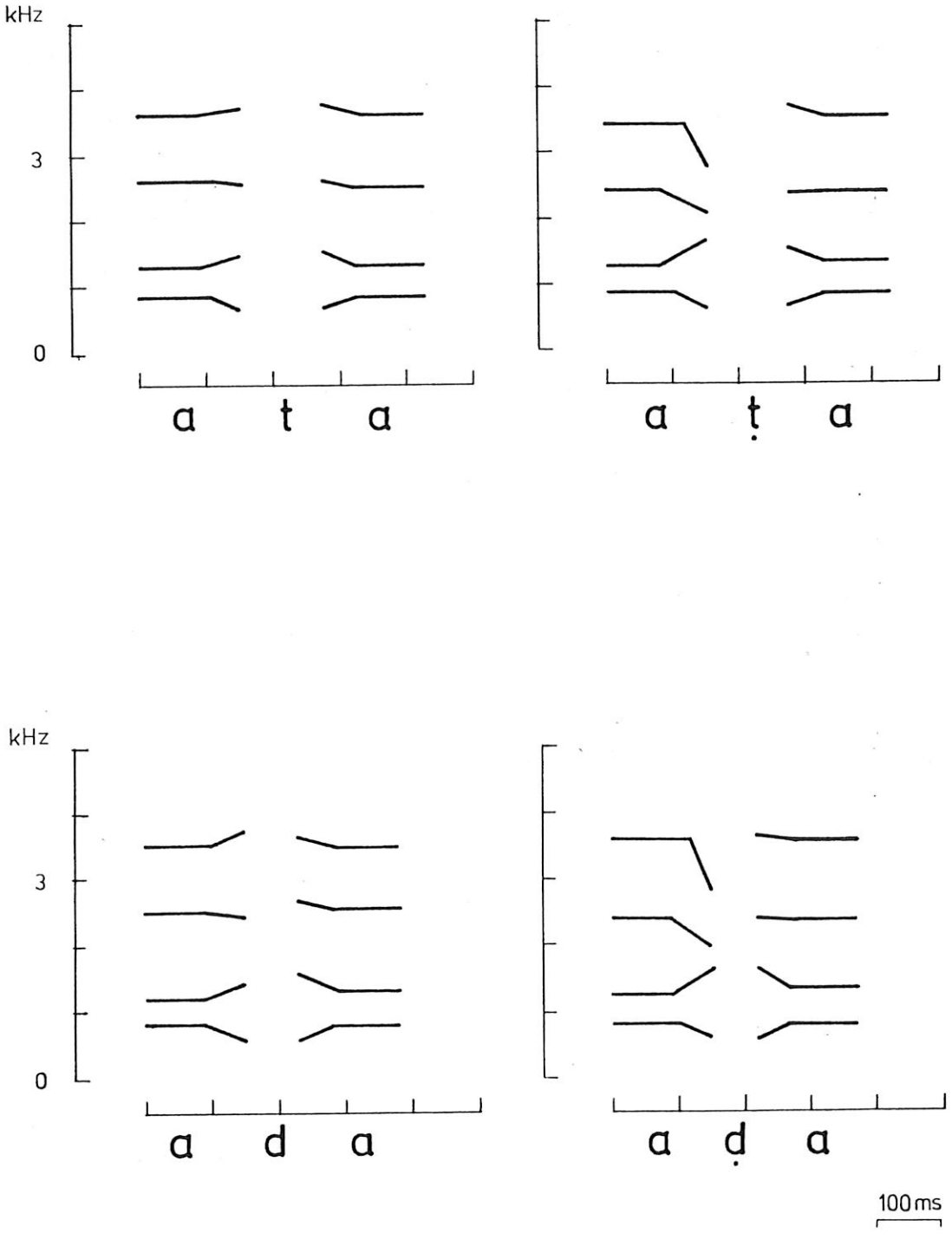


Figure IV.87. Schematic drawings of formant transitions.

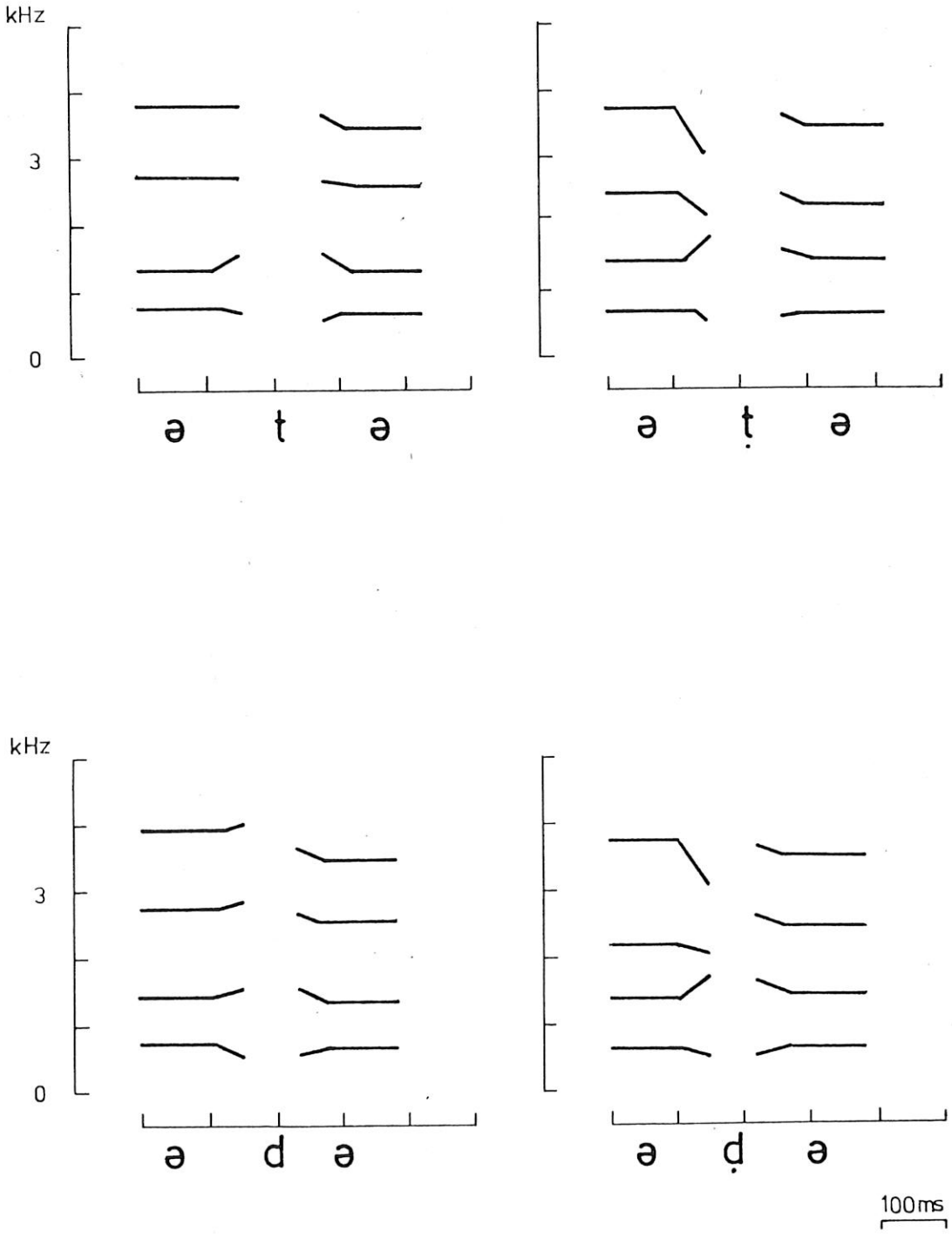


Figure IV.88. Schematic drawings of formant transitions.

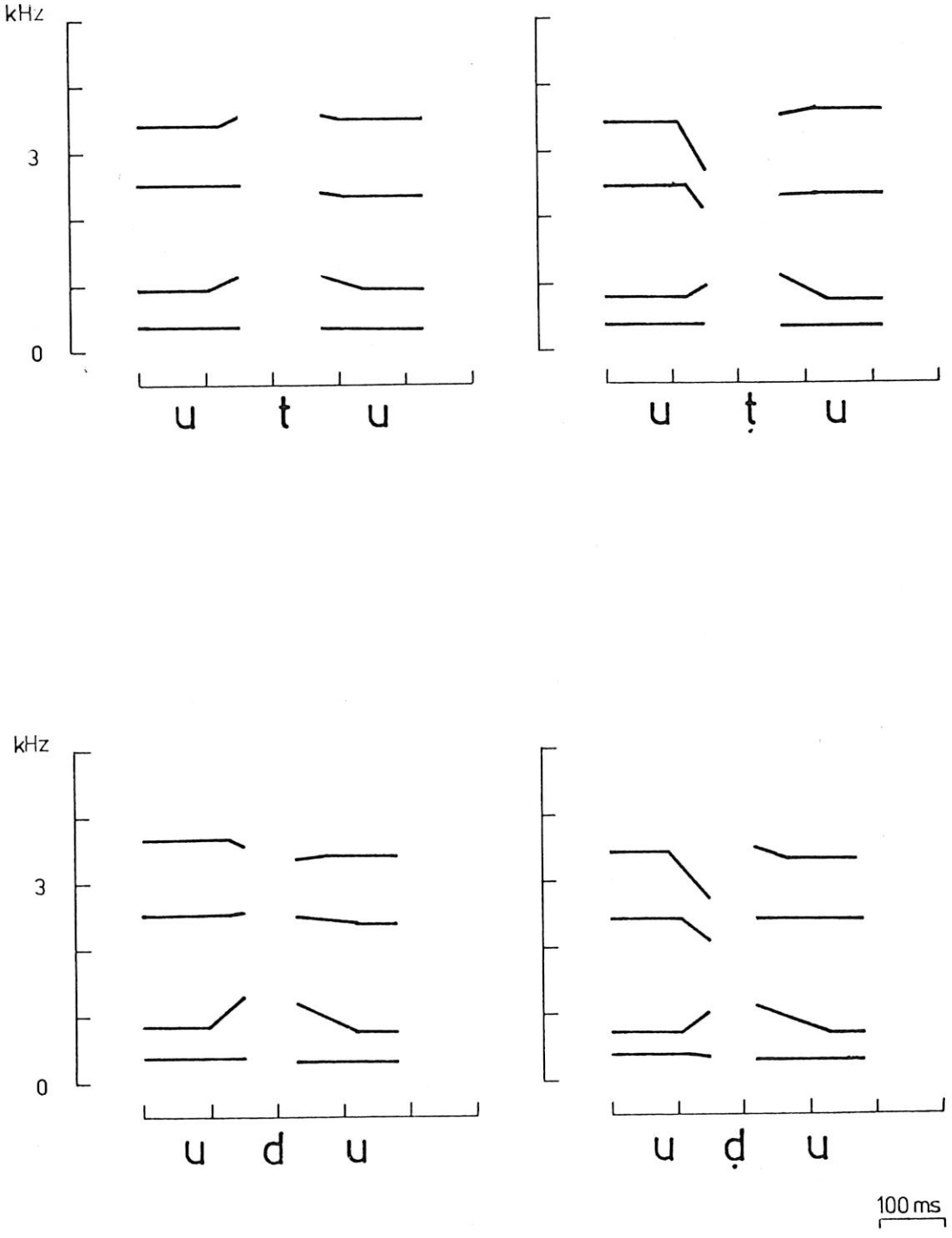


Figure IV.89. Schematic drawings of formant transitions.

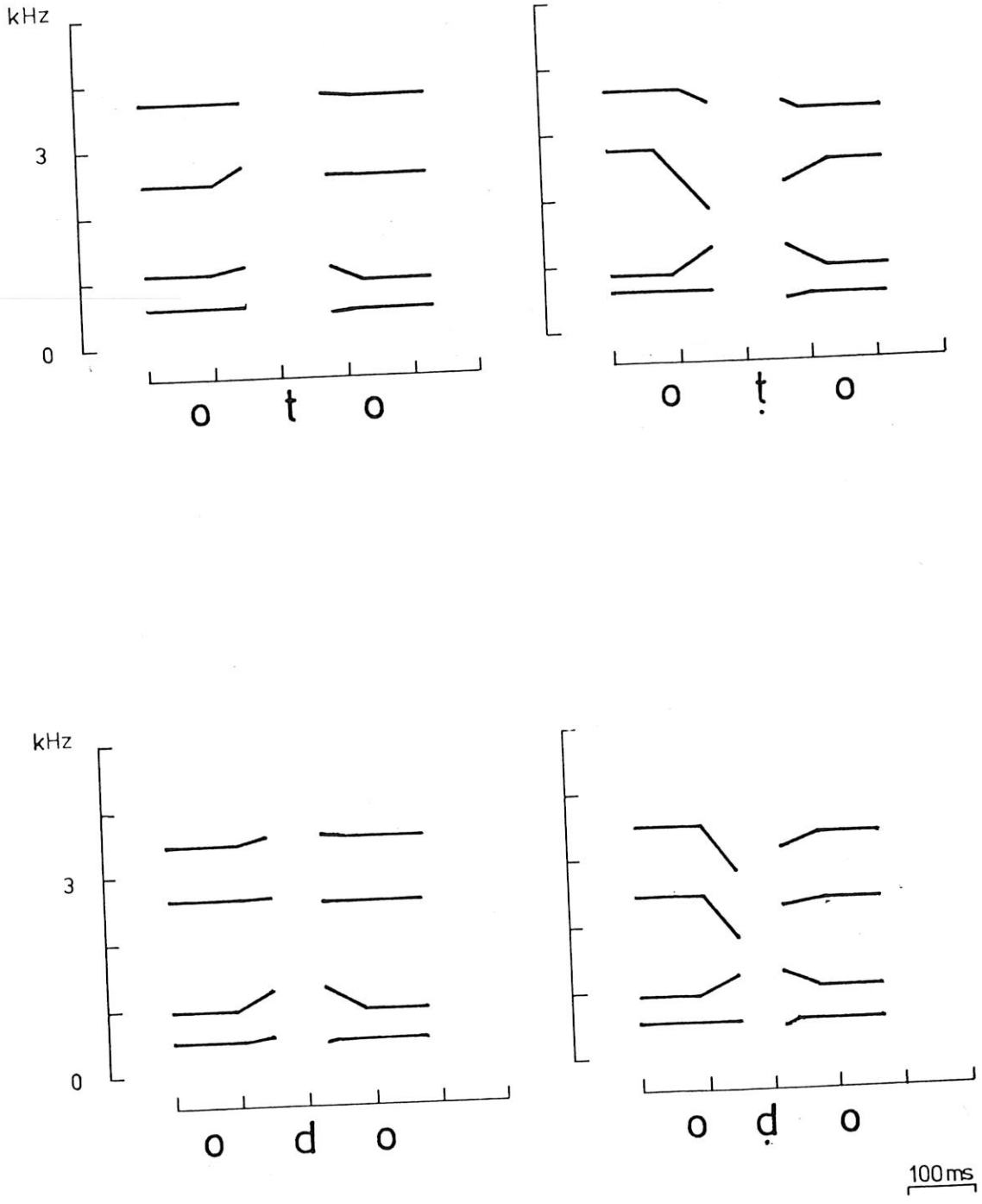


Figure IV.90. Schematic drawings of formant transitions.

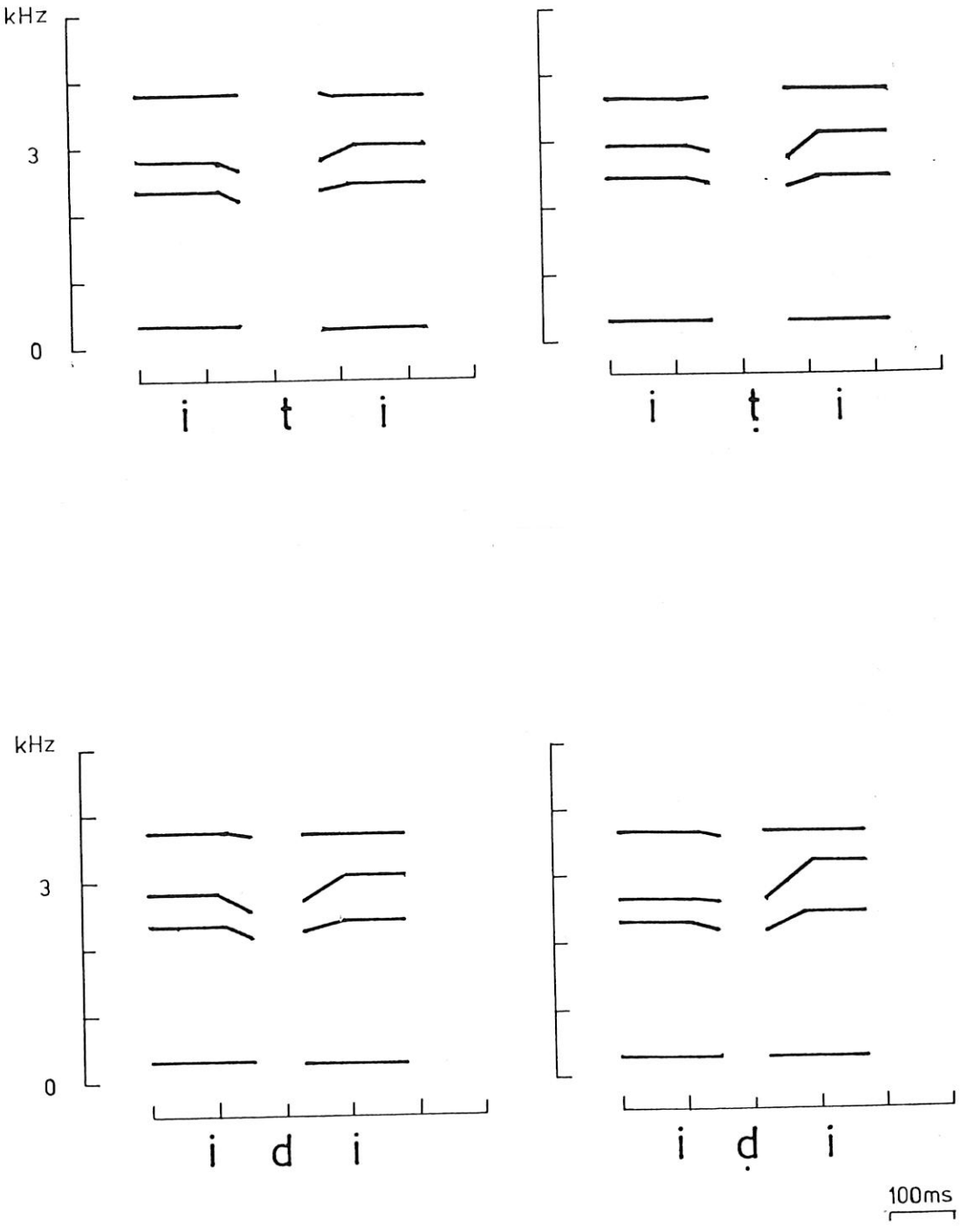


Figure IV.91. Schematic drawings of formant transitions.

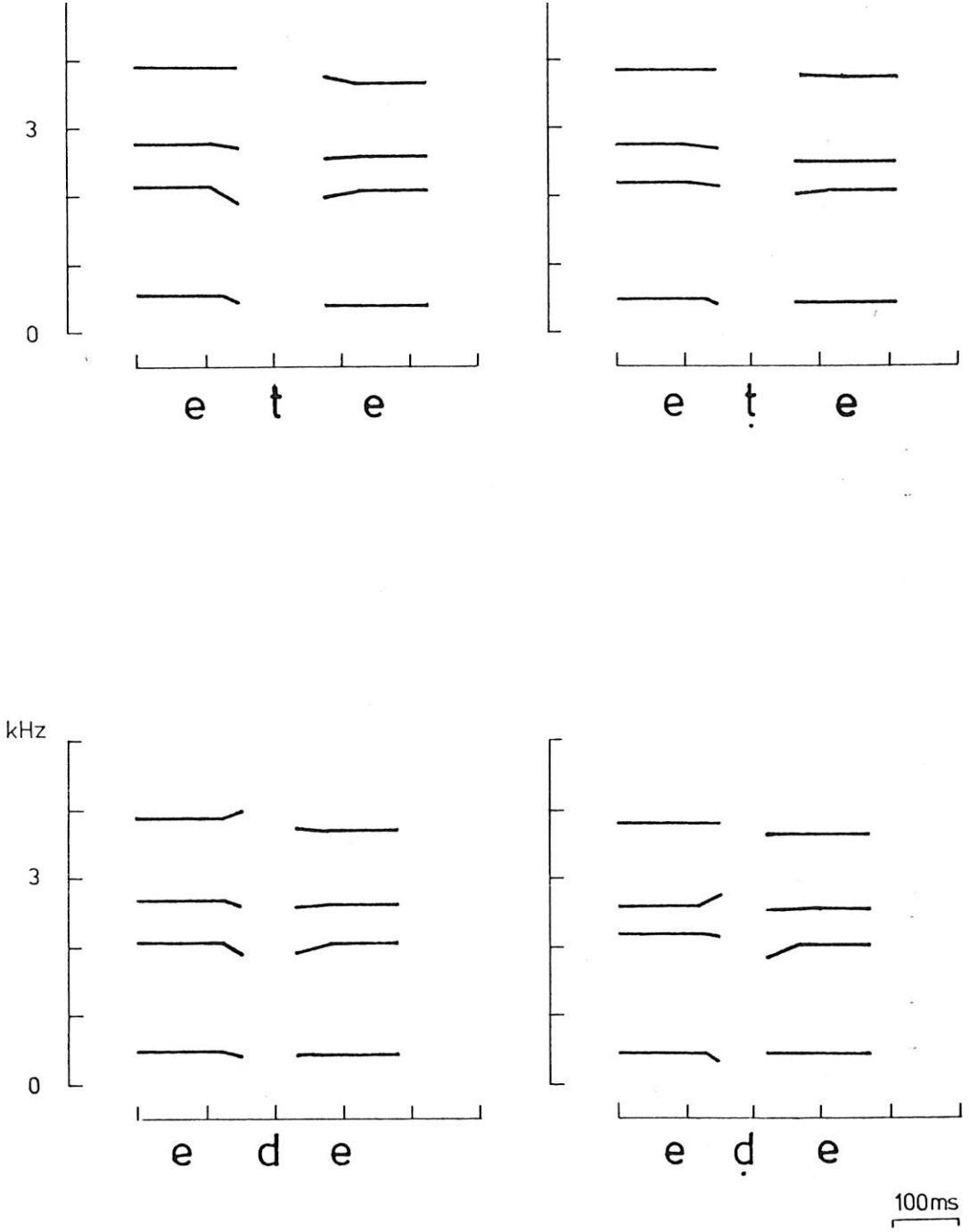


Figure IV.92. Schematic drawings of formant transitions.

VOT-value than b and d, so that the burst can be isolated in the analysis. It is evident that velars have a lower (and more concentrated) burst than retroflex consonants before a and u.. But before i there is no clear difference to be seen. The spectrograms, however, show clearly that the velars have a stronger and longer burst and a longer VOT-value, and also a different start of the vowel formants. In the velars there is a clear second peak around 4500 Hz. This has also been found in Danish palatovelars (Eli Fischer-Jørgensen 1954).

Formant transitions of adjacent vowels.

The frequencies of the start and end of the formant transitions in vowels adjacent to dental and retroflex stops have been measured on the basis of the spectrograms. On the whole, the results are in agreement with the curves taken by the linear prediction method at the points 10-15 ms. after the burst (see above, IV.2.4). As it was the case with liquids and nasals only RD's spectrograms have been measured, but they have been compared with RT's spectrograms of list I-VII by visual inspection.

The frequencies and extent of the transitions are given in tables 4-9 of Appendix D, and schematic drawings are found in Figs. IV.87-92. Specimens of spectrograms are given in Figs. IV.80-81. and 93-94.

A comparison between formant transitions in vowels adjacent to dental and retroflex consonants shows that vowels a, ə, u, o before the retroflex consonants have a very clear negative transition of F_3 and F_4 and a somewhat higher end point of F_2, whereas the difference is much smaller for i and e, although they show the same tendency. There are 24 single pairs of vowels before dental and retroflex consonants which

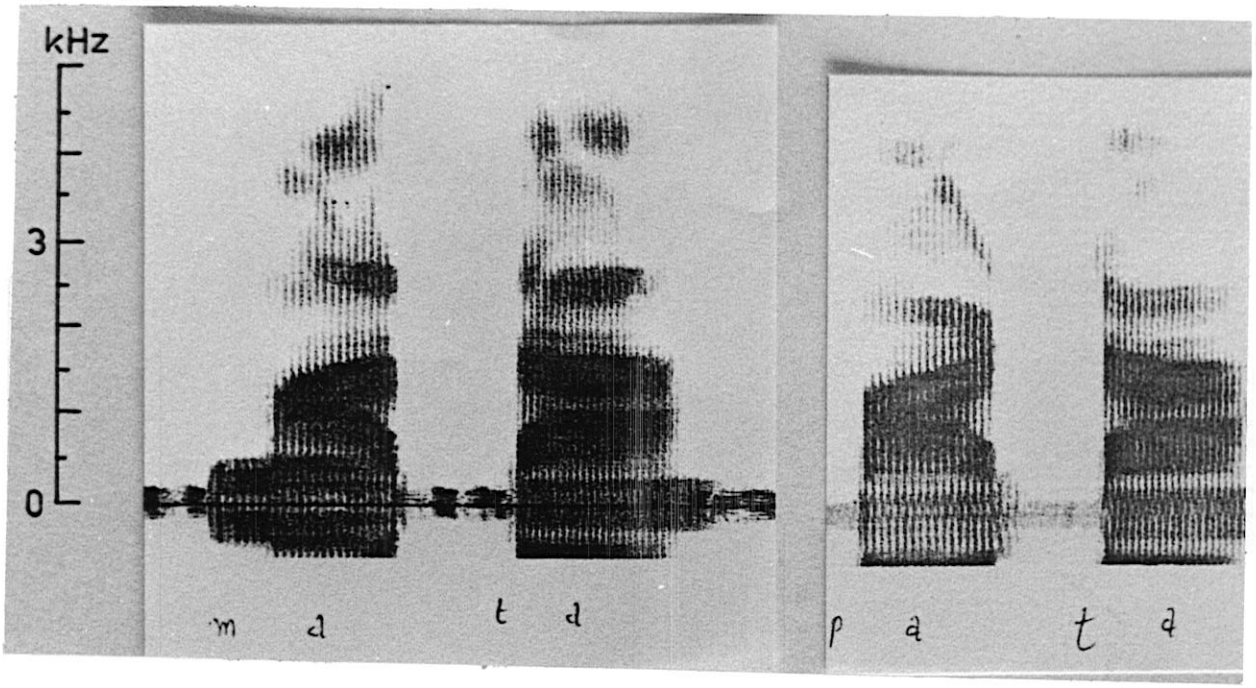


Figure IV.93. Spectrograms of words with t, t̤, d, and d̤ (RD).

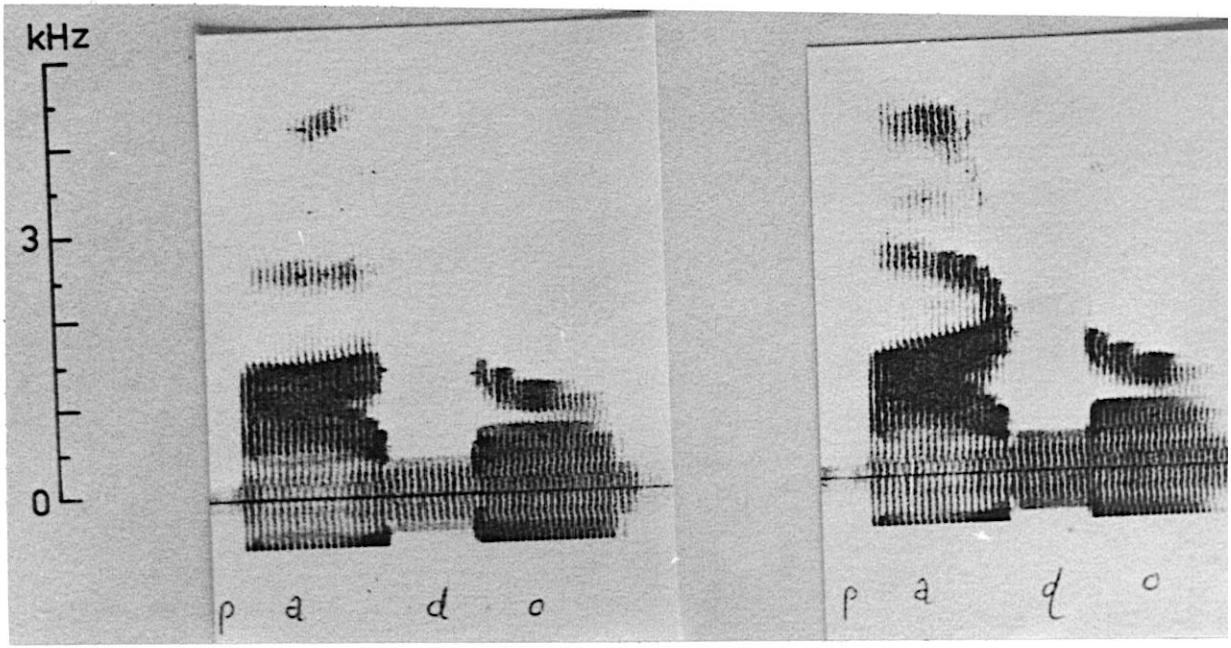


Figure IV.93. Spectrograms of words with t, t, d, and d (RD)

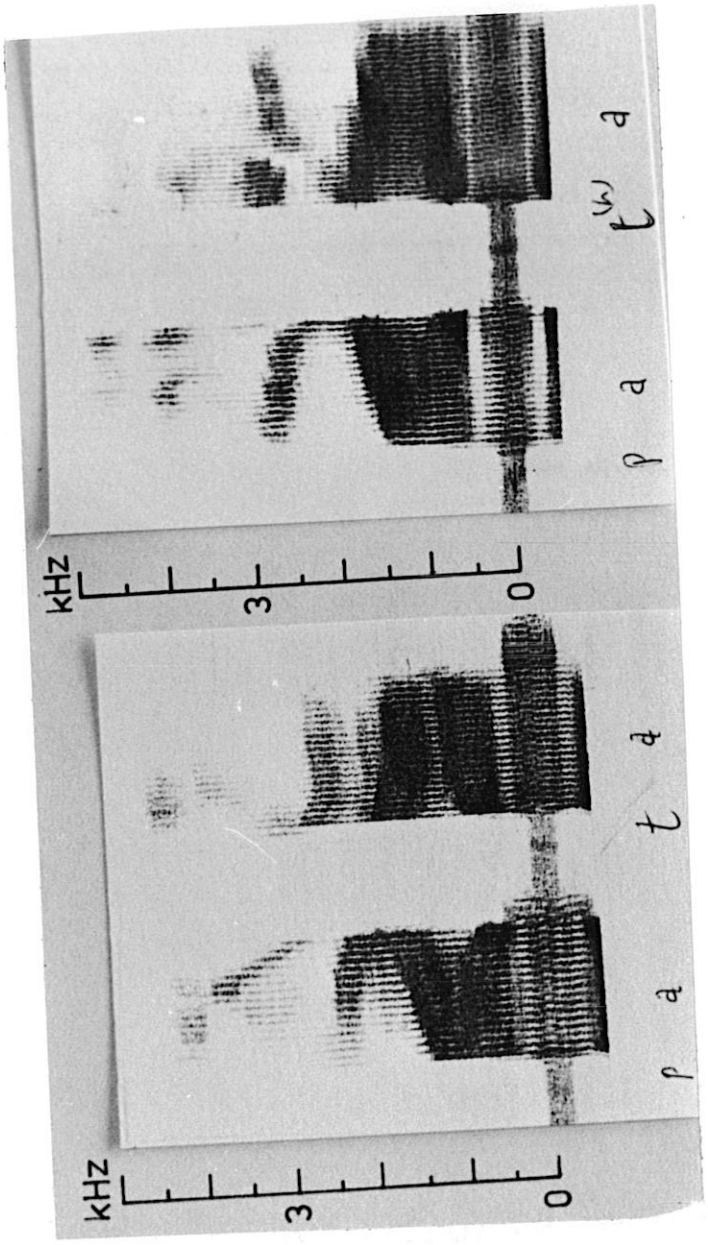


Figure IV.94. Spectrograms of words with t̬ (RD and RT).

F_2 ud and ut. The differences are highly significant for all the vowels taken in one group, but is is evident that the exceptions concerning e and i are systematic. They have negative transitions of F_3 like the others, but the transitions do not go as far down. In one case (ed) the transition of F_3 even goes up, but there was only one example and in this case the following vowel was not e but i, and the positive trantision of F_3 is due to coarticulation with the following i. In this case it was not quite appropriate to combine e+d and d+e into one figure.

The lowering of F_3 and F_4 also affects the steady state frequency of the preceding vowels. This is true in 10 out of 12 averages both for F_3 and F_4. The exceptions for F_3 are ot and it, for F_4 ad and od.

The vowels following dental and retroflex consonants do not show any consistent differences except that o has a lower F_4 after retroflex consonants and a a significantly lower F_3 and a higher F_2 after retroflex consonants.

In Figs. IV.95-97 the average transitions of the formants of preceding vowels have been set up in a graph showing how the formants of different vowels converge.

For F_2 it is possible to set up a locus with tolerable precision. It is evidently higher before retroflex consonants than before dental consonants. If we take the average between the two end points of falling and rising transitions which are closest together, the result is 1672 and 1737 Hz for the dentals t and d, and 1950 and 1958 for the retroflex stops

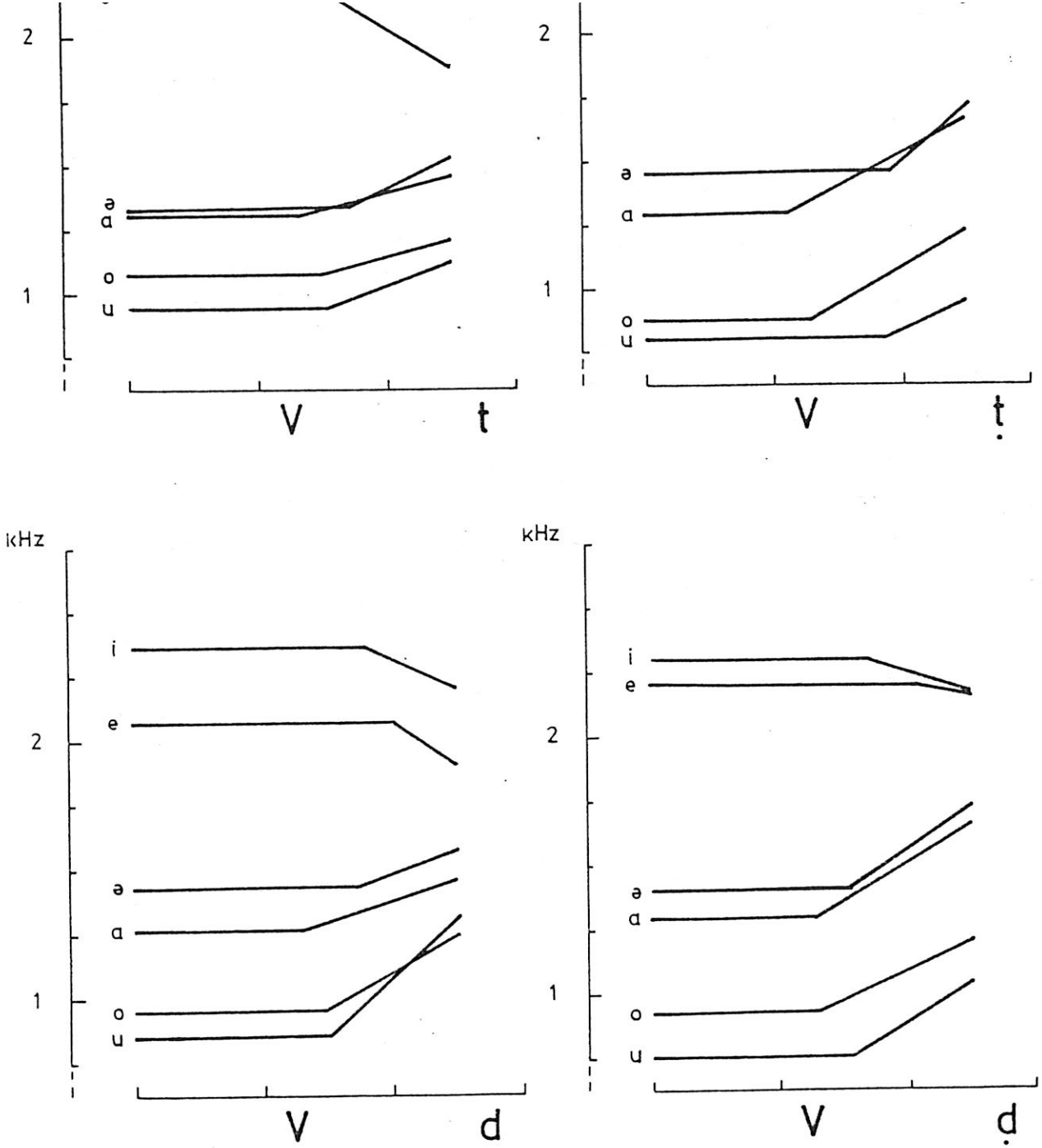


Figure IV.95. Drawings of loci.

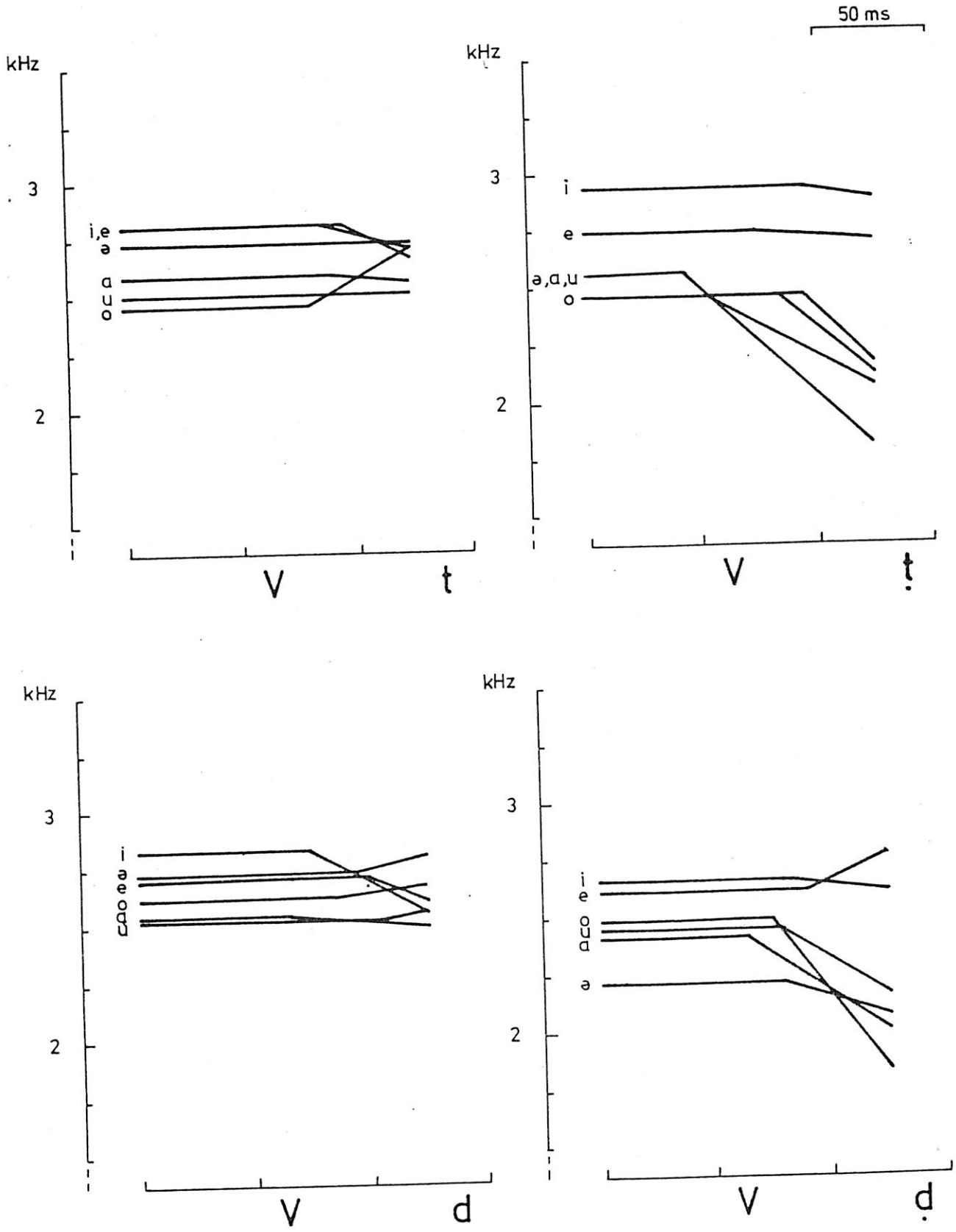


Fig. IV.96. Drawings of Loci.

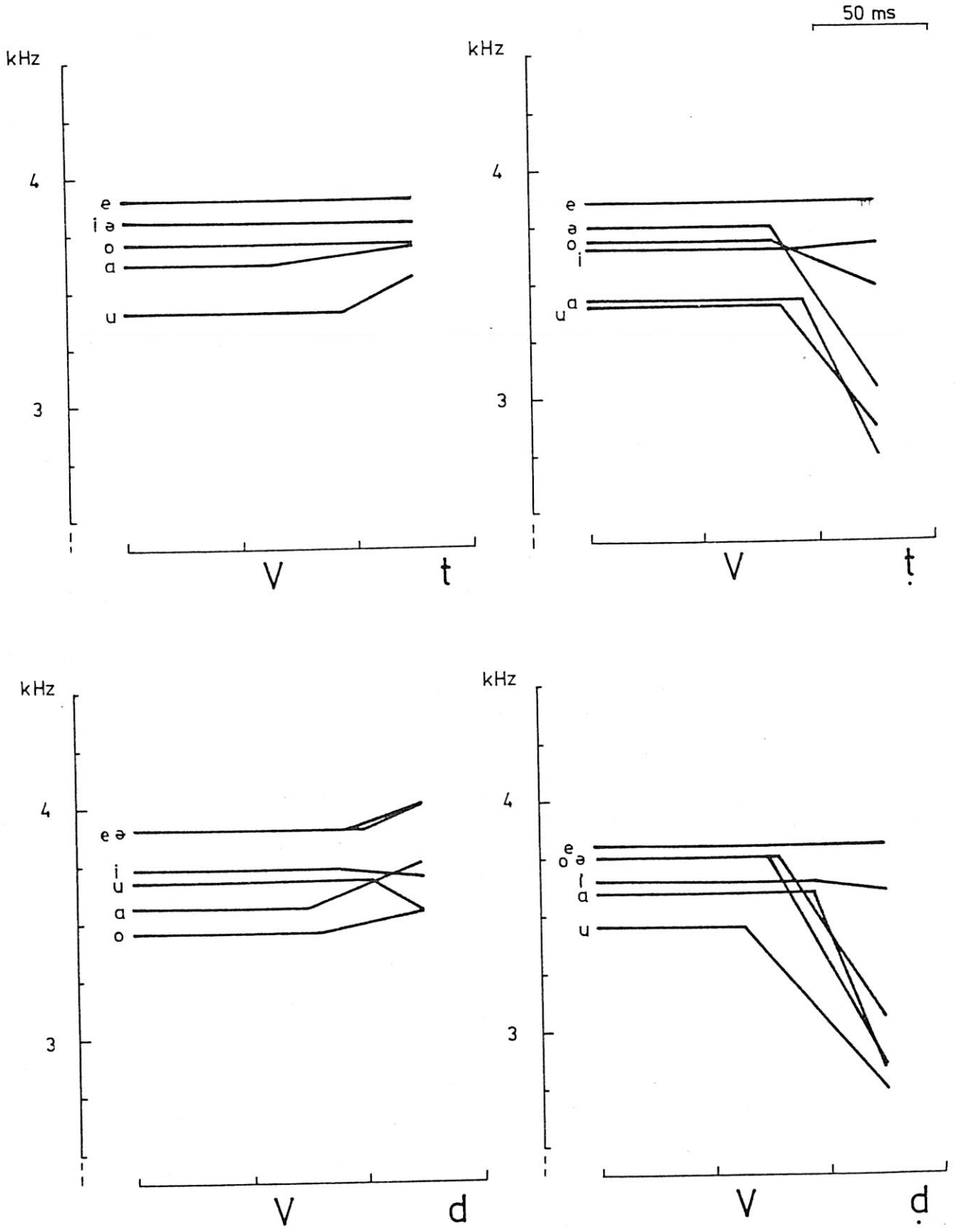


Figure IV.91. Drawings of Loci.

and they should not be expected to, [illegible]

gives 1700 for dentals, and 2000 and 2200 for ṭ and ḍ, respectively. Thus it can be said that there is a locus around 1700 for dentals and 2100 for retroflex stops.

As for F_3 and F_4 the transitions are not as regular, and it can only be said that a F_3 locus for dental ṭ and ḍ must be somewhat below 3000 Hz, approximately at 2700 Hz, which is in good agreement with what has been found earlier. As for F_4 it could be somewhat above 3500, but this is rather guesswork.

F_3 and F_4 in retroflex consonants, on the other hand, do not point to a definite frequency, they simply go steeply downward, except for e and i which show very little inflection at all (e before ḍ goes upwards which is due to coarticulation with a following i, as mentioned above). The lowest point reached by the F_3 transitions is 1800, and that reached by the F_4 transitions is 2750.

RT's spectrograms show quite similar transitions of F_3 in retroflex consonants, but he rarely has any transition of F_4 (see Fig. IV.94).

Comparison with formant transitions in combination with other stop consonants.

List IX, spoken by RD only, also contains examples of labial, dental, and velar stops before the six vowels (in connection with a there are also examples after the vowel). Measurements of vowel transitions after these

consonants are given for the purpose of comparing them with the transitions after dental and retroflex consonants. This was found interesting, particularly because Stevens and Blumstein (1975) have shown that retroflex and velar consonants before a can be synethsized with the same transitions.

The formant transitions of vowels preceding and (in some cases) following labial, velar, and palatal stops are given in tables 10-15 of Appendix D, and schematic drawings are found in Figs. IV.98-103.

There are only a few examples in the material allowing a comparison between the transitions of vowels before dental and retroflex stops with those of vowels preceding other stops, namely a + p, b, k, g, ə + g and i + k. i + k differ celarly from i before dental and retroflex consonants by its positive F_2-transition. ə + g is not very different from ə + dentals, but differs clearly from ə before retroflex consonants because it lacks the negative transition of F_4 and (perhaps less typically) that of F_3. The transitions of a + p, b, k, g differ clearly from those before retroflex consonants because there is no negative transition of F_4, and a + labials differs from both a before dentals and retroflex stops by its negative transition of F_2. But a + k and g are similar to a before dental stops, although F_2 and F_3 come somewhat closer together.

There are examples of all vowels following labial, velar, and palatal stops, but normally only one example of each, so that the results should be taken with some reservation. In this position dental and retroflex stops are less clearly distinguished. None of them can, however, be confounded with palatal stops, since the latter are followed by a long positive F_2-transition of a, ə, o, u. This transition is less

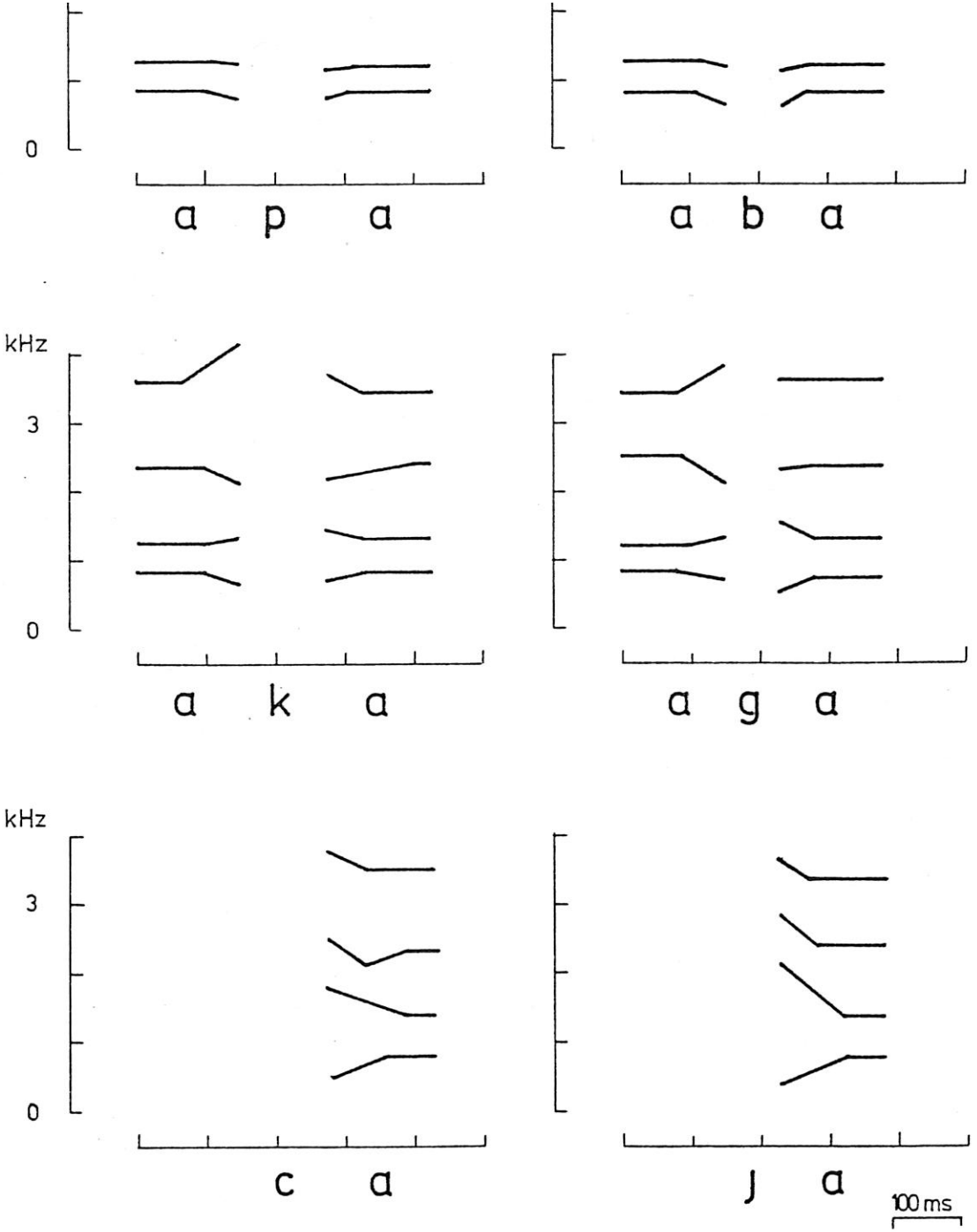


Figure IV.98. Schematic drawings of formant transitions.

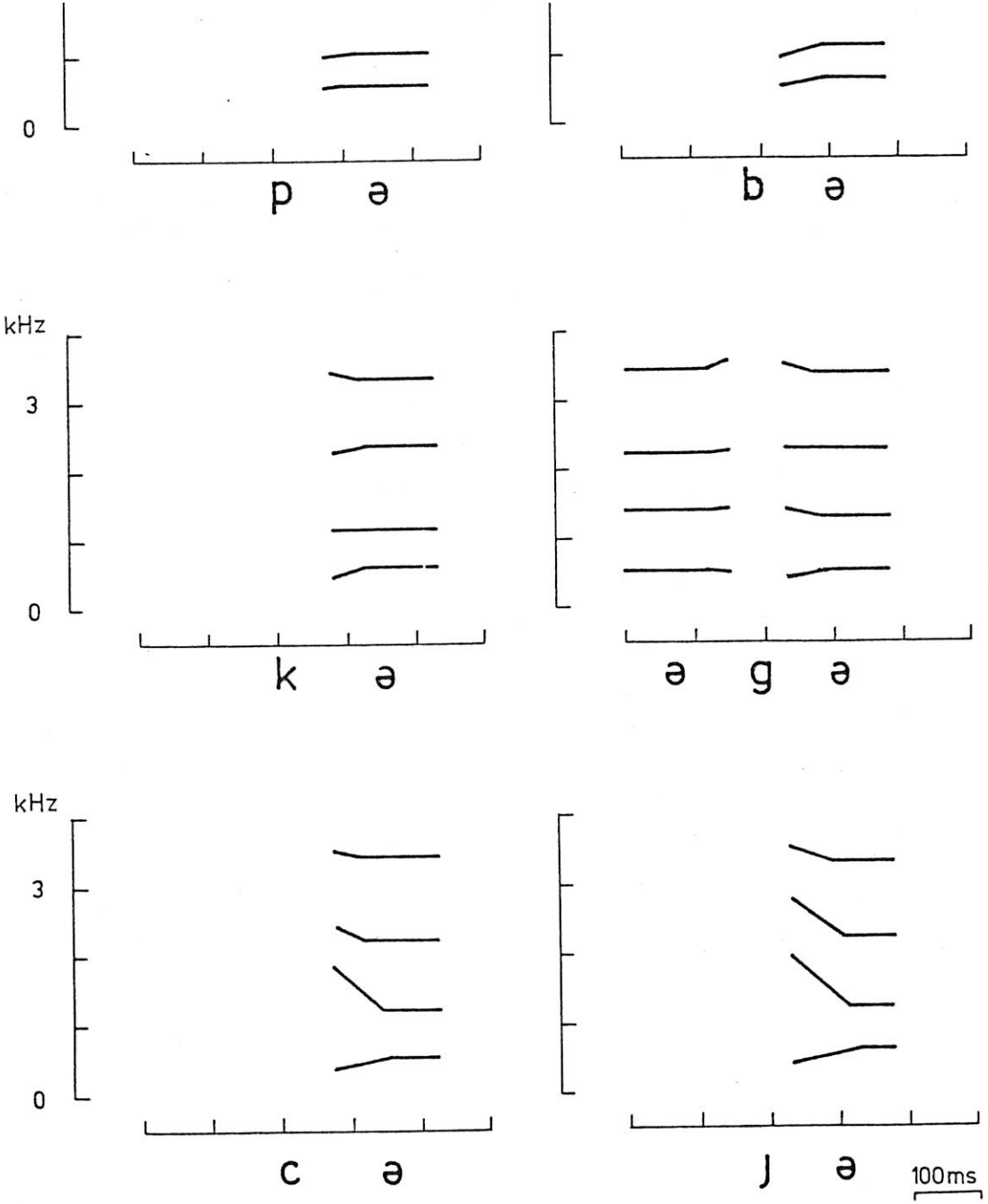


Figure IV.99. Schematic drawings of formant transitions.

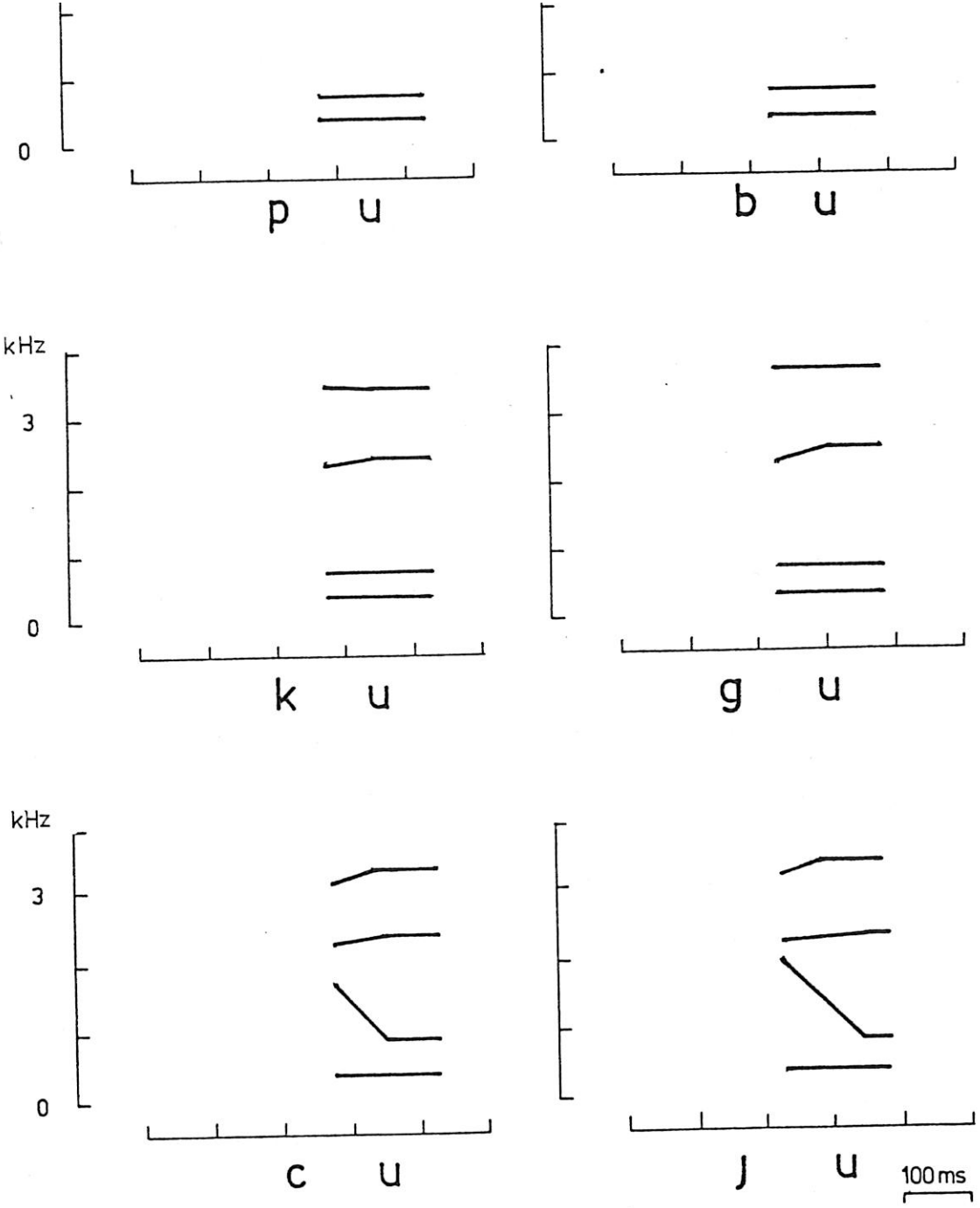


Figure IV.100. Schematic drawings of formant transitions.

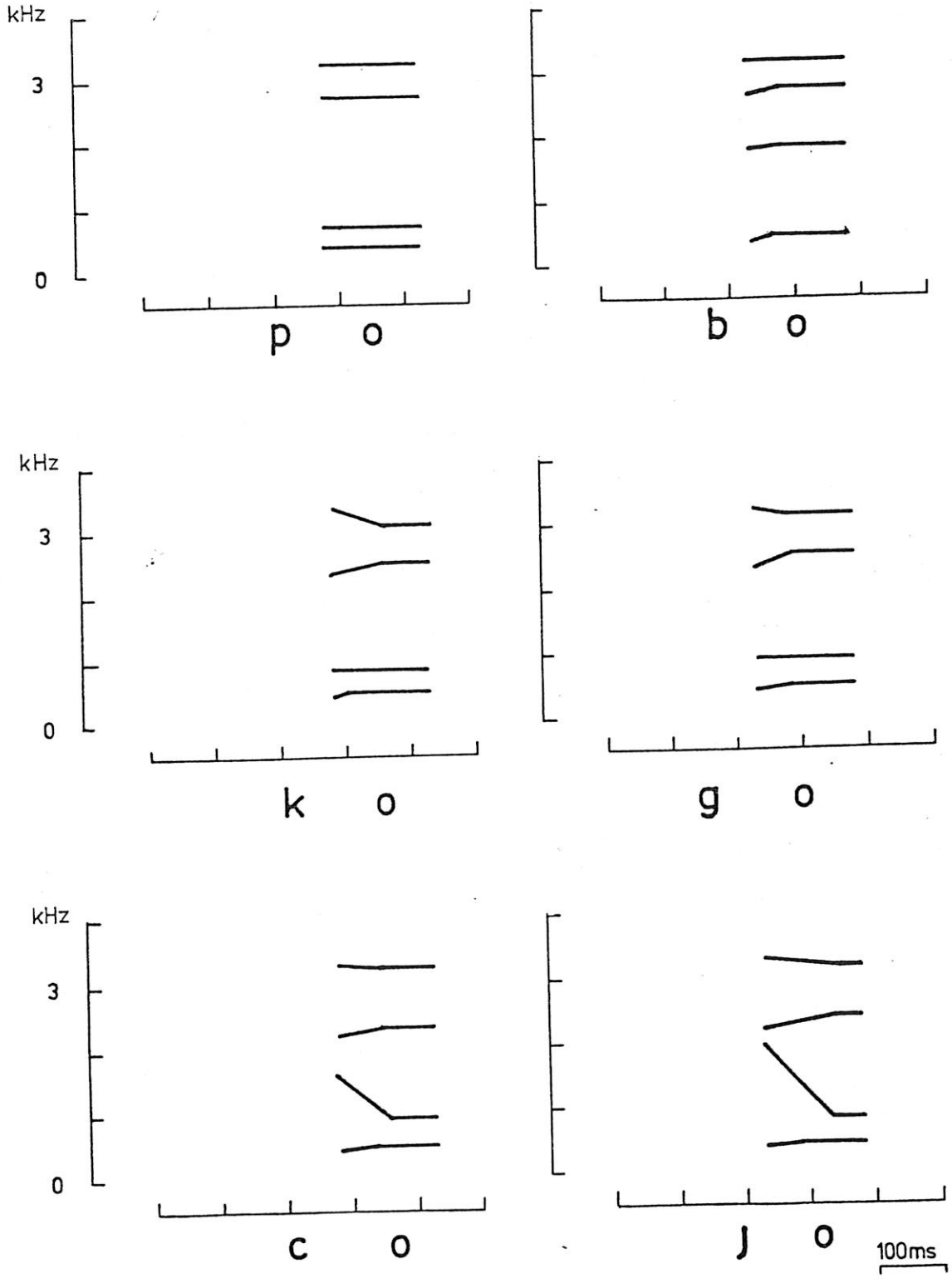


Figure IV.101. Schematic drawings of formant transitions.

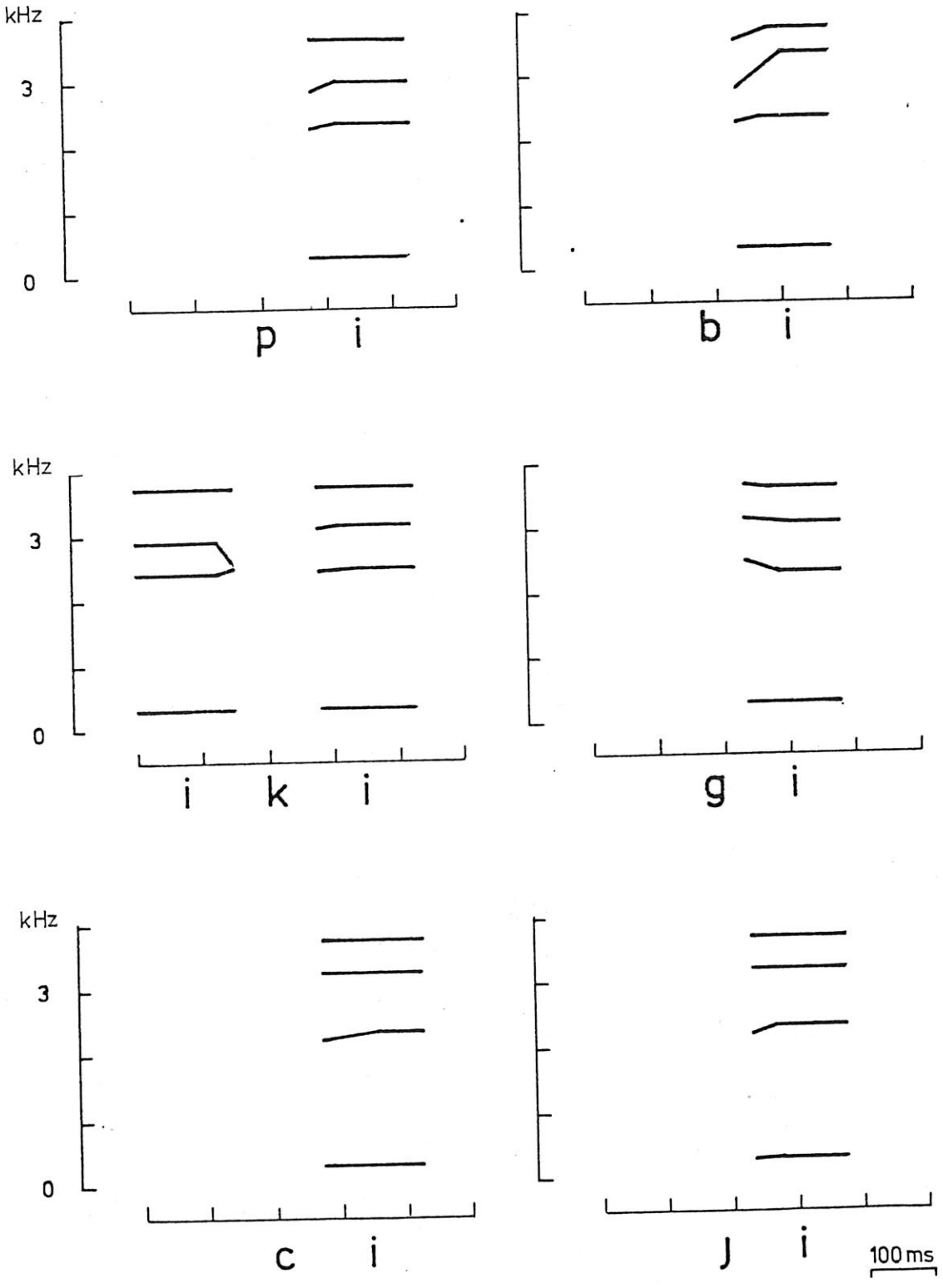


Figure IV.102. Schematic drawings of formant transitions.

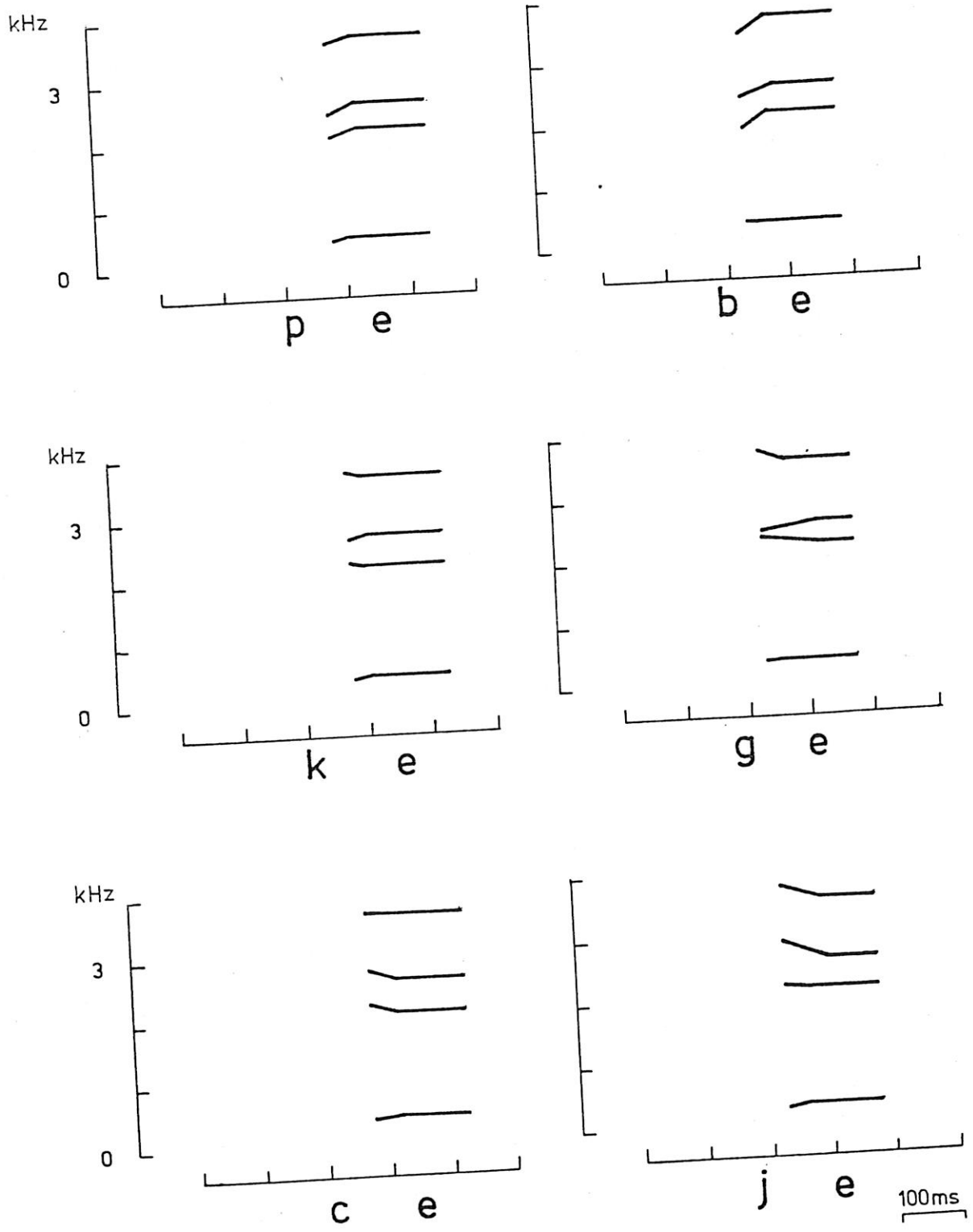


Figure IV.103. Schematic drawings of formant transitions.

pronounced in e, but after dental and retroflex stops e has a falling transition, and ci and ju differ from dentals and retroflex consonants + i by their straight F_3.

As for the labials, they are followed by negative or straight transitions of the vowels. There is thus no possibility of confusion with either dentals or retroflex stops before a, ə, u, and o, which have always positive F_2-transitions, and there is a stronger negative transition in e after labials than after dental and retroflex consonants, but pi and ti do not differ much.

As for the velar stop + e and i they differ from dental and retroflex stops + e and i by having a positive (or almost straight) transition of F_2, and velar stops + u and o differ from dental and retroflex stops + u and o by not having a positive transition of F_2. They differ from dental and retroflex stops + ə by not having a positive transition of F_3. But they do look very similar to retroflex stops + a; both retroflex and velar stops + a have F_2 and F_3 of the following vowel close together. This means that the similarity in formant transitions between velar and retroflex stops is only found after the vowel a, and to a certain extend also before the vowel a.

IV.3 Summary and discussion.

IV.3.1. Comparison with other investigations.

The palatographic analysis of dental and retroflex consonants showed a clear difference in point of articulation between the two categories

in RD's speech. The point of articulation of the dental stops is dental or dentialveolar (in the case of r mostly alveolar), whereas the point of articulation for retroflex consonants normally is prepalatal, but in combination with i rather postalveolar. Retroflex ɭ, ɳ, and ɽ were flapped sounds, and ɭ and ɳ may be very open with only a slight touch in the middle of the palate. The tongue is curled back and touches the palate with the lower surface of the tip.

The acoustic investigation has as its main results that retroflex ɭ and ɳ have a lower F_3 and F_4 (for ɳ F_4 is often missing) than dental l and n, and ɭ has a high F_1 (because of its open and vowel-like articulation). Moreover, all retroflex consonants have a lowering effect on F_3 and F_4 of the surrounding vowels (compared to dental consonants), but particularly on the preceding vowel which has a lower steady state value of F_3 and F_4, but a still more pronounced lowering of the end point of the transition. The effect of stop consonants on i and e is, however, very small. The effect of retroflex consonants on the following vowel is much more irregular but still clear for the vowel a. It may, therefore, not be accidental that retroflex nasals and liquids are not found initially, nor that retroflex consonants are on the whole less common before front vowels (Bhat 1974).

The burst has more energy at lower frequencies before retroflex stops than before dental stops, and for RT there is a peak around 3000 (somewhat higher for i and lower for o).

Compared to the results of Ramasubramanian and Thosar's investigation of Tamil retroflex stops there is agreement on the main point, i.e. F_3 is lowered in vowels adjacent to retroflex stops as compared to dental

stops. There is also agreement in the finding that retroflex ḷ has a lower F_3 than dental l. For retroflex ṇ they indicate a higher F_3 which is somewhat astonishing and not in agreement with the findings of the present investigation. Moreover, they indicate a higher F_2 both in retroflex ṇ and ḷ; this is difficult to compare with the present measurements, since they only give an average value, and F2 differs according to the surrounding vowels. They have not measured F_4.

On the basis of their experiments with synthesis they set up a number of loci, different for front, central, and back vowels (which is not in agreement with the locus concept of the Haskins group), and terminal frequencies fround to be efficient for the synthesis of retroflex stops. or F_3 they have lower loci and lower terminal frequencies of the vowels in retroflex than in dental consonants, but their F_3 locus for dental stops (2000 Hz) seems extra-ordinarily low. For F_2 they assume a higher terminal frequency in a in combination with dental stops than with retroflex stops (1590 vs. 1450 Hz), which is not in agreement with the present measurements. In the table on p. 78 the end points of F_1 of the vowels are indicated as 350 Hz in combination with dentals and 300 Hz in combination with velars both for i, u, and a, although the locus of all consonants is indicated to be 200 Hz and ḭ and u have F_1 at 280. This must be a misprint, which also appears from the schematic drawings of their synethetic stimuli on pp. 83-84.

Still more confusing is what they say about bursts. On p. 78 the poles are indicated to be 3500, 6000, and 4500 Hz for t, 2600, 3900, and 2000 for ṭ, and 3500, 6000, and 4500 Hz. for k; but on p. 82 it is said that the poles for retroflex stops are 3500 and 600 Hz which were

pole, which is in agreement with the [illegible]

for dentals and velars, and 2600 for retroflex stops. It is astonishing that they use the same burst frequencies in front of a, u, and i. A ka and ku with a burst at 3500 Hz are completely unrealiztic, and one wonders how these syllables sound. Nothing is said about the perceptual tests which must habe been used in their experiments with synthesis.

Much more interesting is the article by Stevens and Blumstein (1975). they have taken some spectrograms of t and ṭ in intervocalic position spoken by 3 Hindi speakers. The spectrograms of aṭa reproduced on p. 220 show strongly negative transitions for F_3 and F_4 of the preceding vowel for two of the informants. (The spectrogram of the third informant does not show the hieher formants.) The formants of the following vowels differ, one informant has no rise in F_3 or F_4. This difference between preceding and following vowels with less evident transitions in the following vowel is in agreement with the findings of the present investigation, and so is the negative tranisiton of F_3 and F_4 in the first a. The differences between the bursts which are said to be lower in the retroflex consonant are not very evident in the published spectrograms.

The results of their preceptual tests with synthetic stops in CV syllables with the vowel a are clear. Stimuli with a positive transition of F_3 in combination with a burst between F_3 and F_4 are heard as ta, a straight or negative transition of F3 combined with a somewhat lower burst (between F_3 and F_4) gives ṭa and a lowering of the burst to the

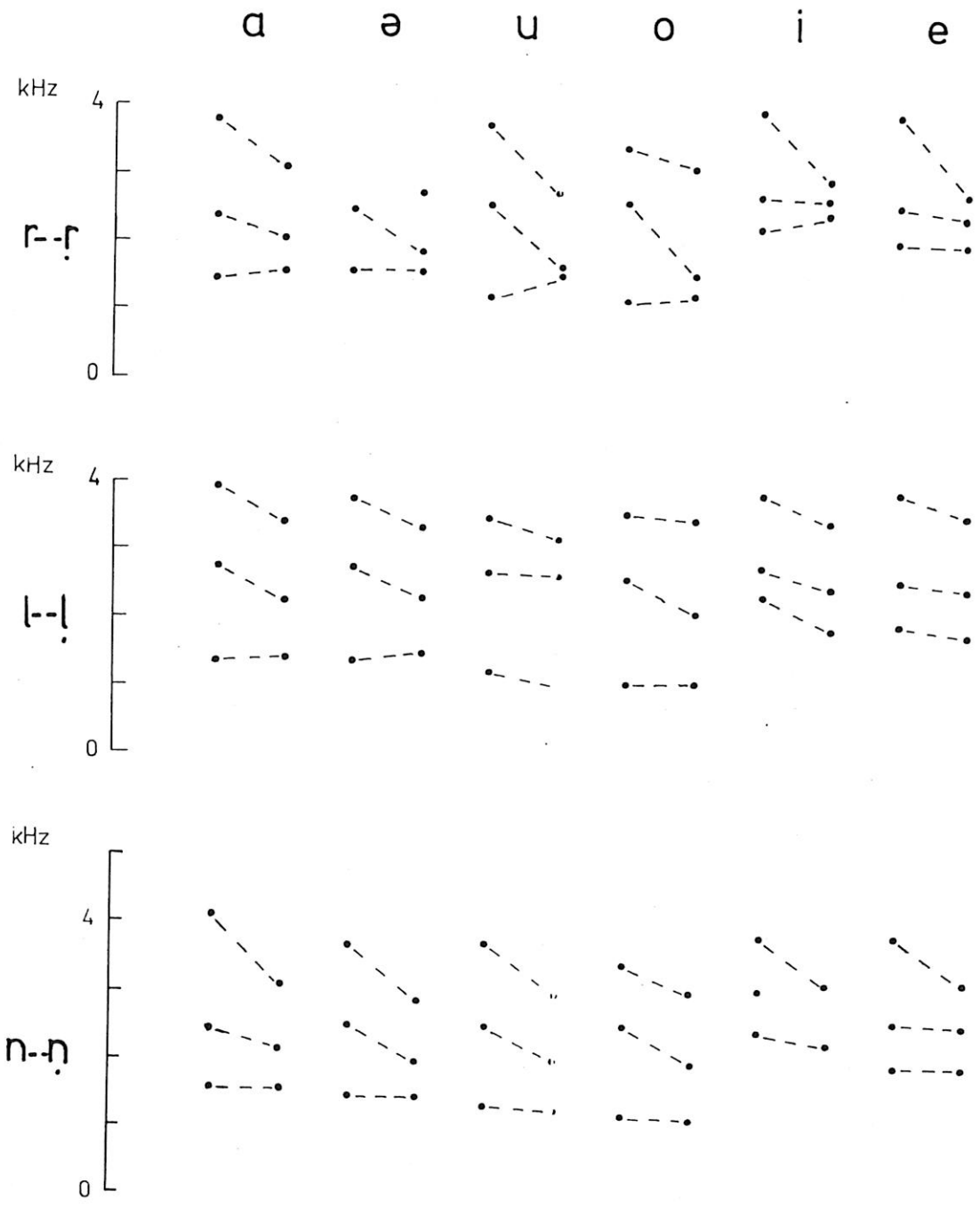


Figure IV.104. Graphic comparison of the end points of formant transitions before dental and retroflex consonants (RD).

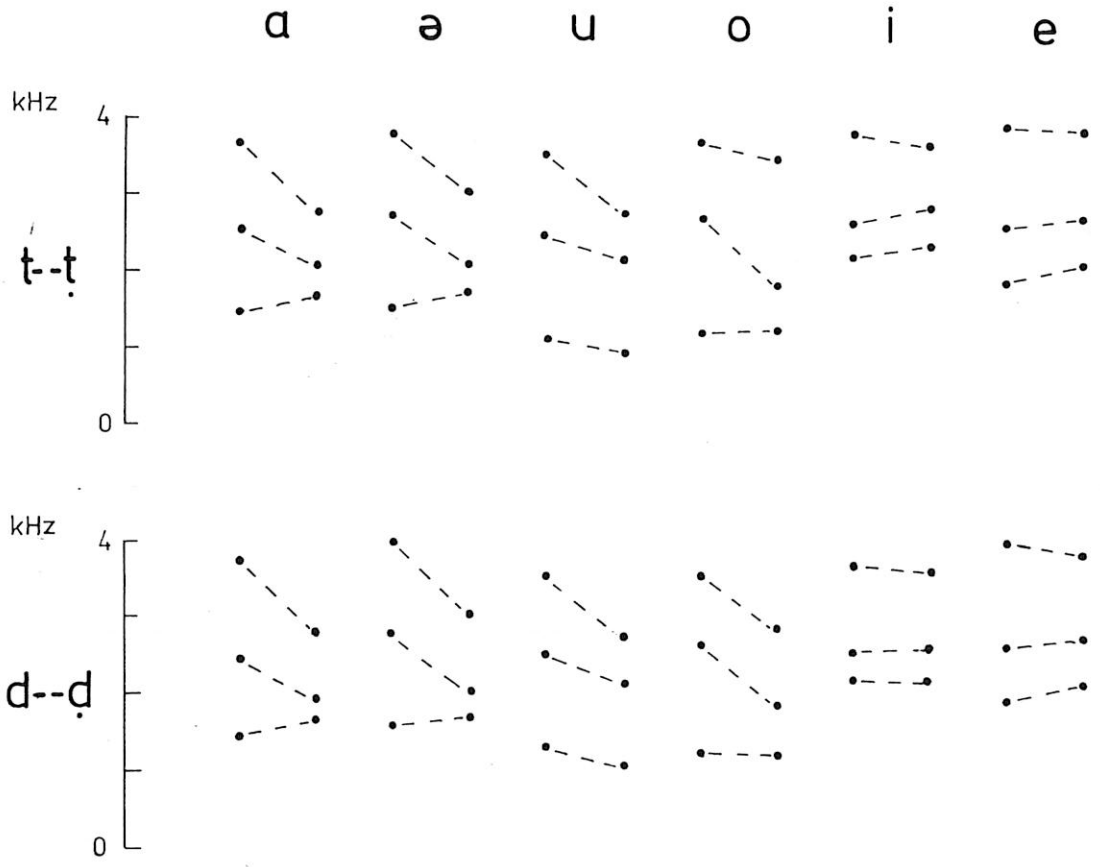


Figure IV.104 (continued).
Graphic comparison of the end points of formant transitions before dental and retroflex consonants (RD).

level of F_3 has the effect that the listener hears ka.

There are, however, some differences between the reactions of the 8 listeners. Some hear ta even when F_3 has a slight positive transition. Since the position of the burst and the transition of F_3 are not varied independently, it is not possible to say what has been more important for the listeners. But is is shown that the addition of a rising F_4 increases the number of retroflex-responses. The main characteristic of retroflex consonants is said to be a clustering of F_2, F_3 and F_4 in a relatively narrow frequency region. In order to illustrate this point the end points of F2, F_3 and F_4 in vowels before dental and retroflex consonants of the present investigation are compared graphically in Fig. IV.104. The tendency is evident although it is not always that F_2 contributes to the result. In this picture the dashed lines do not depict formant transitions; they simply combine the end points of formants before dental and before retroflex consonants to make the difference more clear.

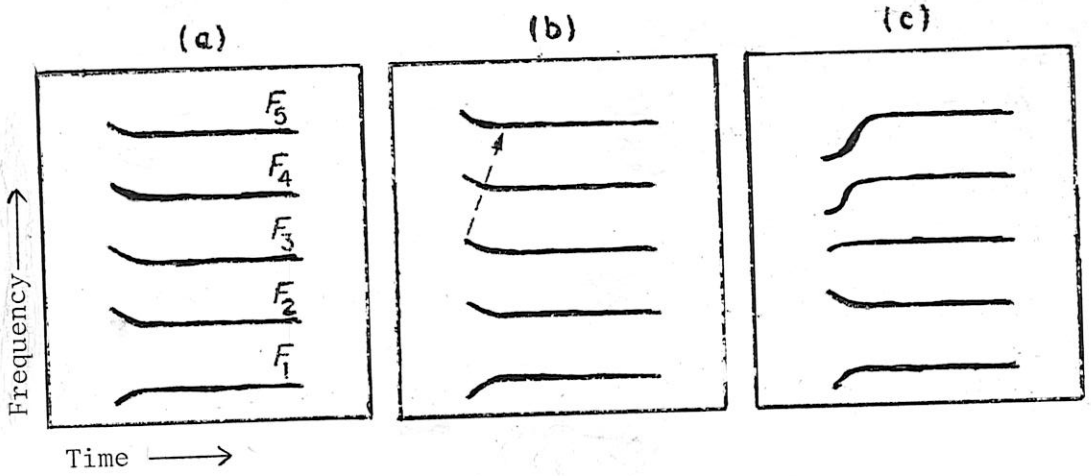
IV.3.2. The relation between articulation and acoustic result.

Stevens and Blumstein also try to explain the acoustic differences between the formant transitions before dental and retroflex consonants on the basis of their production. F_2 in consonants with an apical place of articulation is said to depend on the cavity behind the closure. This may explain why the vowels a and ə were found to have a higher end point of F_2 before retroflex consonants than before dental consonants in this investigation (with ə n as the only exception). When the tongue tip is curled back, the cavity behind the place of articulation gets

shorter and must have a higher resonance (the consonantal section of ḷ has also a higher F_2 after a and ə). For the other vowels this difference is not consistent. For e and i it is found before stops but not before ḷ, r, ṇ. The consonant also seems to play a role. Before r the end point of F_2 is higher (except in er), before ṇ it is only higher in aṇ (and this is only due to the word paṇi which should not have been included in the average).

F_3 and F_4 for the more frontal configuration are - according to Stevens and Blumstein - usually also associated with the cavity behind the constriction in dental consonants, and their end points are generally higher than F_3 and F_4 of the adjacent vowels, so that these get positive transitions. In the present material most fourth formants of the vowels have positive or straight transitions before dentals (see Figs. IV.95-97). But F_3 has negative transitions in i, e, and partly a. i and e seem to have a higher F_3 than the locus for the dental F_3 (this was also found for Danish, see Fischer-Jørgensen 1954).

The cavity in front of the constriction is so small in dentals that it has a very high natural frequency which is no importance. But in retroflex consonants, where the tongue is curled back, the front cavity is larger and, according to Stevens and Blumstein, its resonance comes into the vicinity of F_3 and F_4. When the tongue moves down from the consonant to the vowel the size of the cavity decreases rapidly and the resonance increases rapidly. This is depicted in Fig. IV.105 (Fig. 2 in Stevens and Blumstein 1975). They explain in the text that two formants cannot intersect physically. When they come close together they are displaced upwards and downwards. We thus get a picture with a lowered F_3,



Schematic representation of formant movements at release of consonants produced by raising tongue blade. Part (a) shows falling trajectories of all formants above F_1 for a dental place of articulation; the same trajectories are shown in part (b), together with a dashed line indicating the movement of the front-cavity resonance for a retroflex consonant; the resulting trajectories of the formants at the release of a retroflex consonant are given in (c).

Figure IV.105. (enlarged). (after Stevens and Blumstein 1975)

and a rising F_4 and F_5 in CV syllables. In Stevens (1953) it is shown on the basis of calculations of the resonances of the vocal tract that if the place of articulation is about 12.8 cm. from the glottis (that is slightly behind the dentialveolar place of articulation, F_4 is lowered and comes close to F_3, and the graph shows that still further back F_3 is lowered and comes close to F_2. This is quite in agreement with Fant (1968) who says that retroflex consonants with a postalveolar articulation have F_4 close to F_3, and retroflex consonants with palatal articulation have F_3 close to F_2.

In the palatographic investigation RD's retroflex consonants were found to have a palatal place of articulation, except for the consonants in the environment of i, which has a postalveolar place of articulation. We might therefore expect to find a more exclusive lowering of F_4 rather than of F_3 in the environment of i, and perhaps e. This is on the whole confirmed in the present investigation when the end points before retroflex consonants are compared to those before dental consonants (Fig. IV.104).

We might also look for confirmation of this expectation in a different way: It was mentioned above that RD had a shorter VOT value of his retroflex stops than of his dental stops, whereas this was not the case for RT. Now RD's retroflex stops are generally spoken with the tip of the tongue curled back, and according to stevens (1973) consonants made with the tip of the tongue have a shorter VOT value than those made with the blade because the tip moves more quickly. It might therefore be assumed that RT's retroflex stops were not completely retroflex, but that the blade took part in the constriction. This is in agreement with the

fact that his retroflex stops sound more similar to the dental stops than those of RD. Moreover, the spectrograms of his dental and retroflex consonants were also more similar. But they were more similar because he very rarely has any transition of F_4 (see Figs. IV.69 and IV.94), and if his place of articulation is not as far back he should rather have been expected to have more lowering of F_4 than of F_3.

Finally, it is supposed by Stevens and Blumstein that when the tongue goes down and the front cavity decreased in size and thus decreases its resonance, F_4 should not be influenced until a certain decrease has taken place, about 20 ms after the release. Conversely, it might be expected that when the tongue tip moves up to the retroflex position we should first see a fall in F_4 and then in F_3 as it comes close to the palatal place of articulation. But this is not the case. The steep rise of F_4 generally starts immediately after the release, and the fall of F_4 in the preceding vowel generally starts later than the fall in F_3. In a single case (RD's pili, Fig. IV.106) there is first a downward transition of F_3 in the first i, and then a downward transition of F_2 (and conversely in the second i). This really looks as if there is a cavity which increases gradually in size, first incluencing F_3 and then F_2. But similar pictures are never found for F_4 and F_3.

We have thus had some difficulties in applying the very plausible explanations given in Stevens and Blumstein to our material. But that may be due to the fact that the relations between cavities and formants are extremely complicated, and F_3 and F_4 may be influenced by both the back and front cavities. Sometimes the quickly descending "F_4" transition before a retroflex stop seems to be rather independent of the

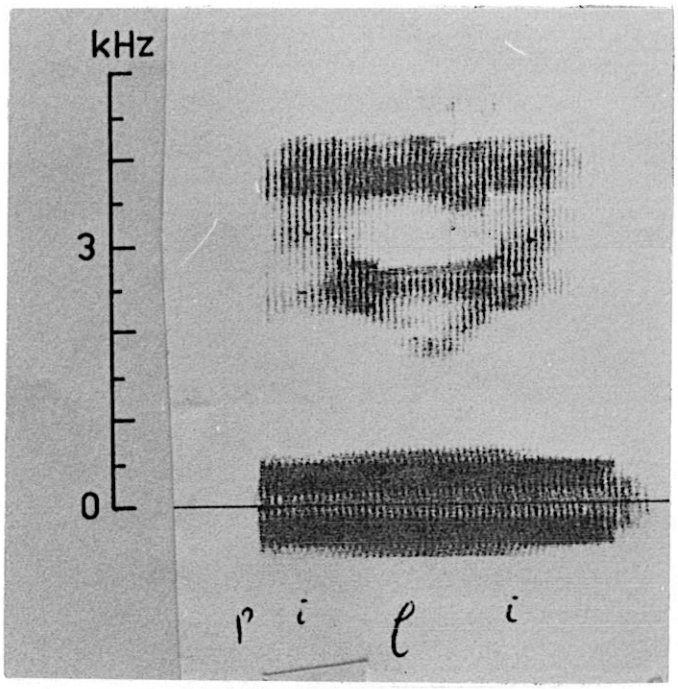


Figure IV.106. Spectrogram of pili (RD).

regular F_4 formant (see Fig. IV.93, pa̤ta).

Stevens and Blumstein do not mention the asymmetry in the spectrograms of retroflex stops, i.e. the fact that the lowering of F_3 and F_4 is much more pronounced in the preceding than in the following vowel. Asymmetries can also be found in connection with other consonants, but they are much more evident in connection with retroflex stops. A glance at the figures IV.59-61, 63-64, 66-67, and 87-97 is enough to state that the transitions of preceding and following vowels are much more symmetric in combination with dentals than in combination with retroflex consonants. This may probably be explained by two things: (1) the movement up to the place of articulation is probably slower than the movement down; (2) when the closure is made with the lower surface of the tip, the contact is probably moved somewhat forward before the tip goes down. In the flapped consonants it is evident that the tip slides forward along the palate. This means that at the release the place of articulation is less retracted, the size of the front cavity already decreased, and the transitions will not be so clearly different from those of the dentals. This is also the explanation given by Bhat (1974). Bhat also mentions that in a tap consonant like alveolar r the tip may move inward so that it ends in a more retroflex position. This is confirmed in the spectrograms of r in the present investigation, which may sometimes show a rising F_4 in the following vowel, whereas the retroflex r̤ has a falling F_4 in the preceding vowel (see Fig. IV.59. ərə and ər̤ə).

IV.3.3. The distinctive features of retroflex consonants.

According to Roman Jakobson retroflexion belongs together with

rounding and pharyngealization as different manifestations of the feature "flat" (see Jakobson, Fant, Halle, 1952, pp. 34 and 49). Acoustically flat phonemes are characterized by a downward shift and/or weakening of some of their upper frequency components. This description is in full agreement with the lowering of F_4 and F_3 found in the present investigation as well as by Ramasubtamanian and Thosar, and by Stevens and Blumstein. Articulatorily they are said to be produced by a decreased back or front orifice of the mouth resonator and a concommitant velarization which expands the mouth resonator. (Jakobson, Halle, 1968, pp. 431-432). In Jakobson-Fant-Halle (1952) an elongation of the mouth esonator is mentioned as the most important characteristic. The description still needs verification. It is not improbable that the hollowing of the tongue body behind the tip in the retroflex articulation entails a certain velarization, even an alveolra r̤ is considered to entail a certain velarization, but to confirm this assumption it would be necessary to make X-ray photos of retroflex consonants. The picture given in Stevens and Blumstein (1975) of Polish retroflex d̤ does not show any velarization, nor any elongation of the mouth cavity. And the physiological explanation of the lowered F_3 and F_4 given by Stevens and Blumstein is not based on the cavity behind the constriction, but on the cavity in front of the constriction. This point needs more investigation.

APPENDIX A

Lists 1 and 2 used as texts for the formant analysis of Gujarati vowels.

List 1

Group A. Words with clear vowels.

(1) i

(2) itər 'another'

(3) is 'upper end of bedstead'

(4) lin 'engrossed (in)'

(5) lila 'girl's name'

(6) tithi 'day of the month'

(7) din 'day of the week'

(8) e

(9) ela 'hello" (address)

(10) ek 'one'

(11) tel 'oil'

(12) teli 'oil man'

(13) theli 'small bag'

(14) tethi 'therefore'

(15) ə

(16) əttər 'perfume"

(17) əgər 'a salt-pan'

Group A. Words with clear vowels. (continued)

(18) təl 'sesanum'

(19) təle 'under'

(20) təsu 'a kind of measurement like centimeter etc.'

(21) a

(22) ag 'fire'

(23) asən 'seat'

(24) dal 'pulses' (grain)

(25) dada 'grandfather'

(26) tato 'sharp' (masc.)

(27) bap 'father'

(28) pamer 'wretched'

(29) papi 'sinful'

(30) o

(31) op 'polish, brightness'

(32) ok 'vomit' (II Imp.sg.)

(33) mobh 'crossbeam'

(34) bobṛo 'stuttering man' (adj.)

(35) popət 'parrot'

(36) u

(37) ug 'grow' (II Imp.sg.)

(38) upaṛ 'demand'

(39) kup 'well' (n.)

(40) kubo 'small cottage'

(41) bhumi ground, earth'

Group B. Words with nasalized vowels.

(42) ĩ

(43) əhĩ 'here'

(44) təhĩ 'there'

(45) sĩh 'lion'

(46) chĩk 'sneeze'

(47) lĩk 'that which comes out of the nose'

(48) Ẽ

(49) tẼ 'you' (sg. Agentive)

(50) hẼ 'what? please?'

(51) Ẽt 'credit'

(52) mẼ 'I' (agentive)

(53) khẼc 'shortage'

(54) śẼ 'how'

(55) ə̃

(56) sə̃jwari 'broom'

(57) hə̃s 'swan'

(58) kə̃s 'a king's name'

(59) də̃g 'surprised' (adj.)

(59a) tə̃g 'disgusted' (adj.)

(60) mə̃nda 'girl's name'

(61) ə̃ntər 'distance'

(62) sə̃ṅgh 'group'

(63) sə̃ncəy 'collection'

(64) ə̃ṅk 'lap'

Group B. Words with nasalized vowels (continued)

(65) ã

(66) ãk 'sieve'

(67) kã 'why'

(68) pãkh 'wing'

(69) lãpi 'putty'

(70) kãp 'manure'

(71) sã 'which' (neut. pl.)

(72) õ

(73) bhõk 'pierce' (II Imp.sg.)

(74) põk 'parched grain'

(75) bhõ 'ground, earth'

(76) bõter 'seventy-two'

(77) sõp 'consign' (II Imp.sg.)

(78) lõkṛi 'an animal'

(79) ũ

(80) bhũk 'bark' (II Imp.sg.)

(81) sũ 'what'

(82) gatũ 'singing' (neut.sg.)

(83) ũṭ 'camel'

(84) tũ 'you' (sg.)

(85) hũ 'I'

List 2

Group C (a). Words with clear and murmured vowels in pairs.

(86) kəṛi 'hook'

(87) kə̤ṛi 'curry'

(88) bi 'seed'

(89) bi̤ 'be afraid of'

(90) cir 'clothes'

(91) ci̤r 'tear' (II Imp.sg.)

(92) pelo 'that' (Pro.masc.sg.)

(93) pe̤lo 'first' (masc.sg.)

(94) sej 'bed'

(95) se̤j 'a little'

(96) mek 'put' (II Imp.sg.)

(97) me̤k 'fragrance'

(98) bar 'twelve'

(99) ba̤r 'out'

(100) maro 'beat' (II Imp.pl.)

(101) ma̤ro 'mine, my' (masc.)

(102) mor 'peacock'

(103) mo̤r 'mango blossom'

(104) koṛ 'longing'

(105) ko̤ṛ 'leprosy'

(106) por 'last or next year'

(107) po̤r 'a period of three hours'

(108) doṛ 'run' (II Imp.sg.)

(109) do̤ṛ 'one and a half'

Group C (a). (continued)

(110) dudh 'milk'

(111) dụd 'milk'

(112) ũgh 'sleep'

(113) ũg 'sleep'

(114) wali 'name of a monkey king'

(115) wạli 'dear' (fem.)

(116) ko 'someone'

(117) kọ 'say' (II Inp.sg.)

Group C (b).

The same words are spoken in reverse order. Group C (c) included the words with clear vowels, and Group C (d) included the words with murmured vowels. Group C (e) included words in phases and sentences.

Group D. Some words for RT.

(a) and (b): Words with clear and murmured vowels.

(i) paṛ 'obligation'

(ii) taro 'star'

(iii) mal 'goods, property'

(iv) lawo 'bring' (II Inp.pl.)

(v) boḷũ '(I may) immerse'

(vi) mel 'dirt'

(vii) səwar 'horseman'

(viii) ɒer 'revenge'

(ix) pÕci 'wristlet'

Group D (b)

(x) pạr 'mountain'

(xi) tạro 'your' (masc.sg.)

(xii) mạl 'enjoy' (II Imp.sg.)

(xiii) lạwo 'enjoyment, pleasure'

(xiv) bọlu 'large, big'

(xv) mẹl 'palace'

(xvi) sə̀war 'morning'

(xvii) ɔẹr 'dust of the woods'

(xviii) pOci 'reached' (II Imp.sg., fem.)

Group D (c) and (d) included phrases and sentences with the clear and murmured vowels, respectively.

APPENDIX B

TABELS SHOWING THE MEASUREMENTS OF CLEAR, NASALIZED, AND MURMURED VOWELS.

Table B.1 SK. Averages of clear and nasalized vowels (List I.A-B)

No.	Samples	No. of samples	F_o	F_s	F_1	F_2	F_3	F_4
1.	i	(9)	130		263	2358	2989	4000
2.	ĩ	(5)	143		255	2758	3250	4033
3.	e	(6)	131	(225) (1)	420	2200	2783	3820
4.	ẽ	(6)	132	237	671	2221	2825	3683
5.	a	(8)	118	(204)	747	1409	2212	(2983?)
6.	ã	(6)	126	238	779	1375	2137	(3650?) (1)
7.	ə	(5)	128		603	1330	2455	(3800?) (1)
8.	ə̃	(4)	130	239	706	1250		3683
9.	o	(5)	127	(222)	493	770		
10.	õ	(6)	126	242	630	905	(2800?) (1)	
11.	u	(5)	128		313	721		
12.	ũ	(6)	142		253	625	(2300?) (1)	2862

Table B.2 RD. Averages of clear and nasalized vowels (List I.A-B)

No.	Samples	No. of samples	F_o	F_s	F_1	F_2	F_3	F_4
1.	i	(6)	135		274	2358	2900	3804
2.	ĩ	(5)	139		278	2620	3203	3940
3.	e	(5)	132	(205)	427	2166	2660	3890
4.	ẽ	(6)	133	283	627	2190	2775	3927
5.	a	(9)	124	(204)	849	1315	2525	3211
6.	ã	(6)	130	290	932	1314	2379	3442
7.	ə	(5)	131	(210)	595	1450	2475	3794
8.	ə̃	(4)	130	236	785	1360	2462	(3600?) (1)
9.	o	(5)	131	(200)	474	912	(2450?) (2)	3450
10.	õ	(6)	134	256	617	949	2528	3542
11.	u	(5)	131		330	816	(2500?) (1)	
12.	ũ	(6)	133		268	678	2612	

Table B.3 RT. Averages of clear and nasalized vowels. (List I.A-B)

No.	Samples	No. of samples	F_o	F_s	F_1	F_2	F_3	F_4
1.	i	(6)	169		277	2104	2558	3312
2.	ĩ	(5)	177		255	2430	3060	3350?
3.	e	(6)	147		357	1896	2530	3454
4.	ẽ	(6)	169	222	748	1971	2667	3450
5.	a	(8)	142		781	1196	2537	3200
6.	ã	(6)	165	(205??)	795	1183	(2723?)	3212
7.	ə	(5)	160		595	1225	2500	3256
8.	ə̃	(4)	157	224	701	1175	2644	3382
9.	o	(5)	164		396	880	2606	3235
10.	õ	(6)	161	256	677	925	2487??	3370
11.	u	(5)	149		276	816	2590	(3250?) (2)
12.	ũ	(6)	186		253	700	2228	(??)

Table B.4 (a) Isolated vowels (List 1.A-B)
(one example of each)

SK No.	Samples	F_o	F_s	F_1	F_2	F_3	F_4
1.	i	145		270	2500	3300	4100
2.	i	130		220	2500	3350	4100
42.	ḭ	144		250	2700	3650	4100
8.	e	135	(270?)	450	2300	2900	3900
48.	Ḛ	135	250	700	2250	2875	3650?
21.	a	125	(225)	775	1400	2225	3425
65.	a̰	130	250	800	1300	2075?	3600?
15.	ə	125		600	1050	2450	3950?
55.	ə̰	125	225	725	1175	2600?	3750
30.	o	130	(240?)	475?	750		
72.	o̰	130	250	675	930??		
36.	u	130		275	650?		
79.	ṵ	130	250	250	700		

Table B.4 (b)

RD

No.	Samples	F_o	F_s	F_1	F_2	F_3	F_4
1.	i	138		265	2400	3000	3750
42.	ĩ	143		275	2640	3275	3900
8.	e	137		375	2200	2800	3750
48.	ẽ	135	270	550	2300	2800	3750
21.	a	125	(220)	870	1250	2450	3100?
65.	ã	132	265	950	1280	2400	3400?
15.	ə	131	(220)	610	1200	2575??	3650?
55.	ə̃	132	270	670	1030	2350	2875?
30.	o	132	(200)	475	900		
72.	õ	140	260	600?	860?	2550?	
36.	u	133		325	650		
79.	ũ	133		280	650	2700	3425?

Table B.4 (c)

No.	Samples	F_o	F_s	F_1	F_2	F_3	RT / F_4
1.	i	170		220	2300	2975	3275
42.	ĩ	205		275	2600	3150	3300?
8.	e	150		330	2000	2600	3450
48.	ẽ	170	250	750	2050	2700	3500
21.	a	160		810	1230	2575	3200
65.	ã	163	(205??)	775	1200	2800	3250
15.	ə	165		600	1000?	2700	3150
55.	ə̃	160	225	825?	1125	2900	3400
30.	o	180		350	825	2600	3100
72.	õ	175	235	625?	850		3350?
36.	u	181		290	750	2600	
79.	ũ	191		250	675?	2250	
(d) No. 56 [sə̃jwari]							
SK		125	225	675	1700		
RD		134	260	680	1350	2400	
RT		160	200	900	1375	2900	3400

Table B.5 SK. Averages of clear and murmured vowels (List II-C)

No.	Samples	No. of samples	F_1	F_2	F_3	F_4
1.	bi, cir	11	270	2409	3027	3954
2.	b̤i, c̤ir	11	272	2394	2959	3802
3.	pelo, sej	8	452	2059	2639	3583
4.	p̤elo, s̤ej	8	478	1962	2631	3607
5.	mEk	5	542	2215	3050	3535
6.	mE̤k	5	555	2205	2925	3585
7.	bar, maro, wali	12	729	1344	2298	3647
8.	b̤ar, m̤aro, w̤ali	9	712	1333	2278	3525
9.	kəṛi	5	562	1397	2208	3422
10.	k̤aṛi	5	545	1378	2238	3675(2)
11.	mor, koṛ por, doṛ, ko	20	493	830	2413	3656
12.	m̤or, k̤oṛ, p̤or d̤oṛ, k̤o	18	494	867	2437	3623
13.	dudh	4	280	942	2575	3825
14.	d̤ud	4	282	908	2550	3687

Table B.6 RD. Averages of clear and murmured vowels (List II-C)

No.	Samples	No. of samples	F_1	F_2	F_3	F_4
1.	bi, cir	8	253	2438	3150	3803
2.	bi̤, ci̤r	8	249	2487	3028	3831
3.	pelo, sej, mek	12	463	2101	2689	3686
4.	pe̤lo, se̤j, me̤k	12	466	2101	2760	3931
5.	bar, maro, wali	11	837	1260	2500	3181
6.	ba̤r, ma̤ro, wa̤li	11	852	1229	2595	3288
7.	kə̤ri	4	564	1363	2298	3725
8.	kə̤ri	4	577	1375	2419	3800
9.	mor, ko̤r, por, do̤r, ko	19	482	872	2505	3348
10.	mo̤r, ko̤r, po̤r, do̤r, ko̤	19	504	911	2607	3273
11.	dudh	4	304	931	2442	3650?(1)
12.	dṳd	4	350	944	2410	3460

Table B.7 RT. Averages of clear and murmured vowels (List II-C and D)

No.	Samples	No. of samples	F_1	F_2	F_3	F_4
1.	bi, cir	8	259	2169	2824	3467
2.	b̤i, c̤ir	7	259	2121	2764	3468
3.	pelo, sej, mel	12	392	1817	2604	3446
4.	p̤elo, s̤ej, m̤el	6	378	1751	2662	3508
5.	mEk	4	485	1887	2700	3419
6.	m̤Ek	2	550	1862	2725	3550
7.	bar, maro wali, paṛ, taro, mal, lawo	22	759	1172	2688	3698
8.	b̤ar, m̤aro, wali, paṛ, taṛo, mal, l̤awo	10	759	1161	2704	3761
9.	kəṛi	4	514	1415	2279	3438
10.	k̤əṛi	4	507	1300	2402	3444
11.	mor, koṛ, por, doṛ, ko, bolũ	22	388	867	2608	3583
12.	m̤or, k̤oṛ, p̤or, d̤oṛ, k̤o, b̤olũ	13	390	882	2650	3633
13.	dudh	4	290	962	2525	3062
14.	d̤ud	3	282	932	2525	2983

APPENDIX C

Word-lists for the consonant research.

List I. (Used for palatograms and spectrograms)

(1) paro 'mercury'

(2) palo 'fodder'

(3) paṛo 'drop' (II.Imp.pl.)

(4) paḷo 'tame' (II Imp.pl.)

(5) paḍo 'male buffalo'

(6) pado 'break wind' (II Imp.pl.)

(7) pal 'a surname'

(8) paṛ 'drop' (II Imp.sg.)

(9) paḷ 'tame' (II Imp.sg.)

(10) par 'end'

(11) pani 'heel'

(12) paṇi 'water'

(13) an 'limit, oath'

(14) aṇ 'bring' (II Imp.sg.)

List II. (Used for palatograms and spectrograms)

(15) tap 'heat'

(16) dab 'press' (II Imp.sg.)

(17) mata 'mother'

(18) mada 'female'

(19) vat 'talk'

(20) vad 'argument'

(21) ṭapu 'island'

(22) ḍaba 'left' (pl.)

(23) paṭa 'bandages'

(24) paḍa 'male buffalos'

(25) aṭ 'a tool of the weaver'

(26) aḍ 'obstruction'

(27) rab 'gruel'

(28) labh 'advantage, benefit'

(29) mara 'mine' (pl.)

(30) pala 'fodder' (pl.)

(31) phaṛa 'pieces of wood'

(32) baḷa 'girl'

(33) ar 'spike'

(34) al 'give' (II Imp.sg.)

(35) phaṛ 'tear' (II Imp.sg.)

(36) phaḷ 'leap'

(37) nabhi 'naval'

(38) mana 'name of a man' (vocative)

(39) paṇa 'stones'

(40) ban 'bail, security'

(41) baṇ 'arrow'

Word No. (21) ṭapu was replaced by ṭap 'sound of the horse-gallop'; nabhi (37) was replaced by nam 'name', and phaḷ (36) by aḷ 'allegation' in 1977.

List II (a) (Used for palatograms and spectrograms)
Words with velar consonants added to the list II in 1977:

(1) kap 'cut' (II Imp.sg.)

(2) paka 'ripe' (masc.pl.)

(3) pak 'crop'

(4) gaw 'sing' (II Imp.pl.)

(5) gəga 'sons' (colloquial)

(6) bag 'garden'

List III. (Used for palatography and spectrography)

(42) iti 'end', 'thus'

(43) sidi 'negro'

(44) piṭi 'beat, hit' (Imperfective III, fem.)

(45) iḍər 'name of a city'

(46) əmiri 'wealthiness'

(47) pili 'pressed' (fem.)

(48) biṛi 'Indian cigar'

(49) piḷi 'yellow' (fem.)

(50) mini 'cat'

(51) əphiṇi 'opium addict'

List III (a) (Used for palatograms and spectrograms)

(1) kiki 'name of a girl'

(2) gəgi 'daughter' (colloquial)

List IV. (Used for spectrograms only)

(52) mete 'by oneself'

(53) umede Agentive of umed (name)

(54) peṭe 'as a part of payment'

(55) eḍi 'heel' (of the foot)

(56) bere 'deaf' (Agentive)

(57) pele 'that' (Agentive)

(58) meṛe 'on the storey'

(59) eḷe 'in vain'

(60) ene 'he, she, it' (Objective, sg.)

(61) eṇe 'he, she, it' (Agentive, sg.)

List V. (Used for spectrograms only)

(62) ətəl 'bottomless'

(63) ədəb 'respect, politeness'

(64) əṭək 'surname'

(65) əḍək 'touch' (II Imp.Sg.)

(66) bhərəm 'illusion'

(67) mələ m 'ointment'

(68) əṛəp 'persistence'

(69) əḷəs 'poverty' (colloquial)

(70) kənək 'gold'

(71) phəṇəs 'Jack fruit'

List VI. (Used for spectrograms only)

(72) roto 'weeping' (masc.sg.)

(73) bodo 'hoarse' (masc.sg.)

(74) oṭo 'platform'

(75) koḍo 'sea-shell' (masc.)

(76) poro 'rest'

(77) bolo 'speak' (II Imp.pl.)

(78) boro 'baldhead' (adj., masc.sg.)

(79) boḷo 'immerse' (II Imp.pl.)

(80) kono 'whose' (masc.sg.)

(81) poṇo 'three-fourth' (masc.sg.)

List VII. (Used for spectrograms only, except for No. 82, hututu)

(82) hututu 'a game'

(83) udar 'generous'

(84) phuṭe 'burst' (Subjuctive, III. sg. and pl.)

(85 uḍe 'fly' (Subjuctive, III. sg. and pl.)

(86) puru 'name of a king'

(87) ullu 'idiot'

(88) suṛa 'parrots'

(89) muḷu 'name of a man'

(90) munnu 'name of a boy'

(91) uṇəp 'lack, deficiency'

List VII (a). (Used for palatograms and spectrograms)

(1) bhodu 'stupid'

(2) uḍũ 'I may fly'

(3) moṭũ 'big' (neut.sg.)

(4) kuku 'voice of the cuckoo'

List VIII. (Used for spectrograms only)

(1) ti ta tu, (2) di da du, (3) ṭi ṭa ṭu,

(4) ḍi ḍa ḍu, (5) te to, (6) ṭe ṭo,

(7) de do, (8) ḍe ḍo, (9) ki ka ku,

(10) gi ga gu

List IX. (Used for spectrograms only)

1. pa
2. ta
3. ṭa
4. ca
5. ka
6. pe
7. te
8. ṭe
9. ce
10. ke
11. pi
12. ti
13. ṭi
14. ci
15. ki
16. po
17. to
18. ṭo
19. co
20. ko
21. ba
22. da
23. ḍa
24. ja
25. ga
26. be
27. de
28. ḍe
29. je
30. ge
31. bi
32. di
33. ḍi
34. ji
35. gi
36. bo
37. do
38. ḍo
39. jo
40. go
41. pu
42. tu
43. ṭu
44. cu
45. ku
46. pə
47. tə
48. ṭə
49. cə
50. kə
51. bu
52. du
53. ḍu
54. ju
55. gu
56. bə
57. də
58. ḍə
59. jə
60. gə

APPENDIX D

Tables of measurements for consonant research.

Table D.1

Formant transitions of vowels adjacent to r and ṛ. (Number of examples in parentheses.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(7)	a + r			(2)	r + a	
F_4	3563	3746	+183	3375	3800	+525
F_3	2593	2362		2275	2175	+100
F_2	1345	1440	+95	1425	1400	+25
F_1	870	605		588	775	-187
(6)	a + ṛ			(3)	ṛ + a	
F_4	3767	3075		3700	3700	0
F_3	2488	2033		2050	2325	-275
F_2	1292	1550	+258	1475	1500	-25
F_1	817	604	-213	641	783	-142
(1)	ə + r			(1)	r + ə	
F_4				2725	3775	-1050
F_3	2450	2450	0	2225	2425	-200
F_2	1425	1550	+125	1575	1550	+25
F_1	650	550	-100	550	725	-175
(1)	ə + ṛ			(1)	ṛ + ə	
F_4	3700	2700	-1000	2775		
F_3	2375	1825	-550	2400	2400	0
F_2	1325	1575	+250	1550	1500	+50
F_1	725	425	-300	525	625	-100

Table D.1 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1)	u + r			(1)	r + u	
F_4	3700	3700	0		3700	
F_3		2550		2500		
F_2	950	1175	+225	1075	875	+200
F_1	375	375	0	350	350	0
(1)	u + r					
F_4	3225	2750	-475			
F_3	2225	1650	-575			
F_2	975	1500	+525			
F_1	375	375	0			
(1)	o + r			(2)	r + o	
F_4	3650	3400	-250	3125	3600	-475
F_3		2575		1750	2100	-350
F_2	925	1150	+225	1200	1000	+200
F_1	525	525	0	575	575	0
(1)	o + r			(2)	r + o	
F_4	3600	3100	-500	3200	3650	-450
F_3	2275	1550	-725	1750	2500	-750
F_2	850	1250	+400	1250	1088	+162
F_1	500	400	-100	525	575	-50

Table D.1 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	$\underline{i} + \underline{r}$			(2)	$\underline{r} + \underline{i}$	
F_4	3950	3950	0	3938	3950	-12
F_3	3013	2675	-338	2663	2988	-325
F_2	2463	2250	-213	2363	2563	-200
F_1	300	300	0	300	300	0
(2)	$\underline{i} + \underline{\dot{r}}$			(2)	$\underline{\dot{r}} + \underline{i}$	
F_4	3700	2900	-800	3950	3950	0
F_3	3200	2650	-550	2825	3300	-475
F_2	2388	2450	+62	2375	2463	-88
F_1	288	288	0	300	300	0
(1)	$\underline{e} + \underline{r}$			(1)	$\underline{r} + \underline{e}$	
F_4	3950	3900	-50	3925	3925	0
F_3	2800	2550	-250	2525	2700	-175
F_2	2300	2020	-280	2050	2225	-175
F_1	450	450	0	475	475	0
(1)	$\underline{e} + \underline{\dot{r}}$			(1)	$\underline{\dot{r}} + \underline{e}$	
F_4	3750	2750	-1000	3950	3950	0
F_3	2800	2400	-400	2550	2600	-50
F_2	2200	2000	-200	2000	2200	-200
F_1	500	300	-200	400	475	-75

Table D.2

Formant transitions of vowels adjacent to l and l̇.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(6)	a + l			(4)	l + a	
F_4	3891	4016	+125	4088	4038	+50
F_3	2579	2716	+138	2599	2494	+75
F_2	1263	1341	+78	1369	1313	+56
F_1	854	650	-204	688	819	-131
(6)	a + l̇			(2)	l̇ + a	
F_4	3754	3379	-375	3638	3800	-162
F_3	2546	2221	-325	2375	2438	-63
F_2	1283	1388	+105	1375	1400	-25
F_1	796	713	-84	725	763	-38
(1)	ə + l			(1)	l + ə	
F_4	3750	3750	0	3600	3200	+400
F_3	2650	2700	+50	2350	2225	+125
F_2	1325	1350	+25	1300	1350	-150
F_1	750	500	-250	750	750	0
(1)	ə + l̇			(1)	l̇ + ə	
F_4	3600	3300	-300	3600	3750	-150
F_3	2350	2225	-125	2550	2700	-150
F_2	1300	1450	+150	1475	1450	-50
F_1	750	750	0	700	700	0

Table D.2 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1)	$\underline{u} + \underline{1}$			(1)	$\underline{1} + \underline{u}$	
F_4	3500	3450	-50	3650	3650	0
F_3		2650		2550		
F_2	950	1200	+250	1300	975	+325
F_1	400	375	-25	425	425	0
(1)	$\underline{u} + \underline{\dot{1}}$			(1)	$\underline{\dot{1}} + \underline{u}$	
F_4	3300	3150	-150	3400	3400	0
F_3	2700	2600	-100			
F_2	800	950	+150	1100	1025	+75
F_1	375	375	0	400	400	0
(1)	$\underline{o} + \underline{1}$			(1)	$\underline{1} + \underline{o}$	
F_4	3650	3500	-150	3600	3550	+50
F_3		2550		2650	2650	0
F_2	950	1025	+75	1100	1050	+50
F_1	500	500	0	550	550	0
(1)	$\underline{o} + \underline{\dot{1}}$			(1)	$\underline{\dot{1}} + \underline{o}$	
F_4	3600	3400	-200	3600	3600	0
F_3	2475	2050	-425	2150		
F_2	850	1050	+200	1050	975	+75
F_1	525	550	+25	600	600	0

Table D.2 (continued)

	Steady start	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	i + 1			(2)	1 + i	
F_4	3825	3800	-25	3850	3888	-38
F_3	2903	2763	-150	2713	2875	-162
F_2	2425	2363	-62	2325	2463	-138
F_1	313	313	0	313	313	0
(2)	i + 1			(2)	1 + i	
F_4	3675	3375	-300	3725	3725	0
F_3	3038	2438	-600	2600	3050	-350
F_2	2350	1850	-500	2050	2325	-275
F_1	300	300	0	350	350	0
(1)	e + 1			(1)	1 + e	
F_4	3850	3850	0	3850	3850	0
F_3	2650	2550	-100	2550	2625	-75
F_2	2250	1900	-350	2000	2100	-100
F_1	525	525	0	500	500	0
(1)	e + 1			(1)	1 + e	
F_4	3725	3500	-225	3750	3850	-100
F_3	2525	2450	-125	2500	2600	-100
F_2	2200	1750	-450	2000	2100	-100
F_1	525	525	0	500	500	0

Table D.3

Formant transitions of vowels adjacent to n and n̥.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(6)	a + n			(4)	n + a	
F_4	4008	4088	+80	4088	4050	+38
F_3	2367	2413	+46	2475	2362	113
F_2	1342	1533	+191	1575	1418	157
F_1	933	863	-70	782	850	68
(6)	a + n̥			(2)	n̥ + a	
F_4	3841	3042	-799	3813	3850	-37
F_3	2250	2150	-100	2237	2300	-63
F_2	1325	1538	+213	1462	1450	+12
F_1	913	946	+33	900	900	0
(1)	ə + n			(1)	n + ə	
F_4	3700	3700	0	3750	3750	0
F_3	2400	2525	+125	2500	2375	-125
F_2	1450	1450	0	1400	1525	+125
F_1	700	750	+50	700	700	0
(1)	ə + n̥			(1)	n̥ + ə	
F_4	3450	2850	-600	3700	3700	0
F_3	2325	1950	-375	2400	2475	-75
F_2	1400	1450	+50	1450	1450	0
F_1	775	775	0	800	800	0

Table D.3 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1)	u + n			(1)	n + u	
F_4	3725	3725	0	3700	3700	0
F_3	2500	2500	0	2600	2600	0
F_2	1200	1325	+125	1100	850	+250
F_1	400	400	0	325	325	0
(1)	u + n					
F_4	3650	2975	-675			
F_3	2600	2000	-600			
F_2	650	1250	+600			
F_1	300	300	0			
(1)	o + n			(1)	n + o	
F_4	3625	3400	-225	3400	3600	-200
F_3	2500	2500	0	2500	2500	0
F_2	1000	1175	+175	1175	1125	+50
F_1	550	675	+125	700	675	-25
(1)	o + n			(1)	n + o	
F_4	3525	3000	-525	3650	3650	0
F_3	2500	1975	-525	2100	2475	-375
F_2	950	1125	+175	1050	1050	0
F_1	550	700	+150	750	725	+25

Table D.3 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	i + n			(3)	n + i	
F_4	3850	3850	0	3925	3925	0
F_3	3262	3075	-187	2950	3208	-258
F_2	2563	2413	-150	2433	2633	-200
F_1	325	325	0	308	308	0
(2)	i + n			(3)	n + i	
F_4	3763	3150	-613	3975	3975	0
F_3				2817	3333	-516
F_2	2425	2288	-137	2267	2638	-371
F_1	313	313	0	338	338	0
(1)	e + n			(1)	n + e	
F_4	3850	3850	0	3825	3825	0
F_3	2650	2600	-50	2700	2800	-100
F_2	2200	1950	-250	2100	2225	-125
F_1	400	400	0	500	500	0
(1)	e + n			(1)	n + e	
F_4	3750	3150	-600	3975	3975	0
F_3	2750	2525	-225	2800	2750	+50
F_2	2250	1925	-325	2000	2125	-125
F_1	400	400	0	550	550	0

Table D.4

Formant transitions of the vowel a adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(4)	a + t			(7)	t + a	
F_4	3613	3688	+75	3750	3607	+143
F_3	2588	2550	-38	2604	2504	+100
F_2	1300	1444	+144	1489	1310	+179
F_1	838	644	-194	661	829	-168
(5)	a + d			(8)	d + a	
F_4	3565	3750	+185	3675	3516	+159
F_3	2530	2485	-45	2700	2575	+125
F_2	1255	1460	+205	1597	1344	253
F_1	845	610	-235	588	825	-237
(4)	a + ṭ			(7)	ṭ + a	
F_4	3425	2763	-662	3700	3564	+136
F_3	2444	2044	-400	2346	2368	-22
F_2	1281	1638	+357	1543	1332	+211
F_1	875	613	-262	668	846	-178
(6)	a + ḍ			(8)	ḍ + a	
F_4	3596	2833	-763	3644	3595	+50
F_3	2410	1995	-415	2406	2388	+19
F_2	1283	1654	+371	1662	1369	+294
F_1	842	613	-229	600	813	-213

Table D.5

Formant transitions of the vowel ə adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1)	ə + t			(2)	t + ə	
F_4	3800	3800	0	3650	3475	+175
F_3	2725	2725	0	2638	2588	+50
F_2	1325	1525	+200	1513	1288	+225
F_1	750	675	-75	563	638	-75
(1)	ə + d			(2)	d + ə	
F_4	3900	4000	+100	3625	3463	+162
F_3	2725	2800	+75	2688	2588	+100
F_2	1425	1575	+150	1525	1363	+163
F_1	725	550	-175	575	625	-50
(1)	ə + ṭ			(2)	ṭ + ə	
F_4	3750	3050	-700	3600	3425	+175
F_3	2450	2100	-350	2425	2275	+150
F_2	1450	1725	+275	1600	1425	+175
F_1	675	525	-150	588	625	-38
(1)	ə + ḍ			(3)	ḍ + ə	
F_4	3750	3050	-700	3625	3517	+108
F_3	2200	2050	-150	2600	2467	+133
F_2	1400	1725	+325	1683	1492	+192
F_1	650	525	-125	517	642	-125

Table D.6

Formant transitions of the vowel u adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	u + t			(7)	t + u	
F_4	3400	3550	+150	3540	3515	+25
F_3	2500	2500	0	2394	2369	+25
F_2	938	1125	+188	1121	939	+182
F_1	375	375	0	371	371	0
(2)	u + d			(3)	d + u	
F_4	3675	3550	-125	3325	3400	-75
F_3	2525	2550	+25	2500	2413	+88
F_2	850	1300	+450	1200	794	+406
F_1	400	400	0	358	358	0
(2)	u + ṭ			(4)	ṭ + u	
F_4	3400	2750	-650	3550	3625	-75
F_3	2450	2150	-300	2325	2350	-25
F_2	800	950	+150	1119	750	+369
F_1	400	400	0	375	375	0
(3)	u + ḍ			(3)	ḍ + u	
F_4	3450	2733	-717	3500	3350	+150
F_3	2433	2133	-300	2475	2475	0
F_2	750	1033	+283	1167	742	+425
F_1	375	375	0	375	375	0

Table D.7

Formant trantitions of the vowel o adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1)	o + t			(3)	t + o	
F_4	3700	3700	0	3775	3750	25
F_3	2450	2700	+250	2541	2533	+8
F_2	1075	1200	+125	1175	925	+250
F_1	600	600	0	475	500	-25
(2)	o + d			(4)	d + o	
F_4	3450	3550	+100	3600	3556	+44
F_3	2613	2638	+25	2606	2600	-6
F_2	950	1243	+293	1294	963	+331
F_1	500	538	+38	450	475	-25
(2)	o + ṭ			(3)	ṭ + o	
F_4	3688	3488	-200	3433	3367	+67
F_3	2550	1825	-725	2242	2533	-292
F_2	875	1225	+350	1267	950	+317
F_1	588	588	0	475	508	-33
(2)	o + ḍ			(5)	ḍ + o	
F_4	3500	2850	-650	3192	3367	-175
F_3	2475	1825	-650	2290	2380	-90
F_2	925	1200	+275	1280	1020	+260
F_1	550	550	0	480	530	-50

Table D.8

Formant transitions of the vowel i adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady start	diff.
(2)	i + t			(5)	t + i	
F_4	3800	3800	0	3785	3765	+20
F_3	2800	2650	-150	2820	3060	-240
F_2	2375	2200	-175	2335	2455	-120
F_1	313	313	0	290	290	0
(3)	i + d			(5)	d + i	
F_4	3725	3692	-33	3705	3715	-10
F_3	2825	2550	-275	2710	3110	-400
F_2	2367	2192	-175	2250	2410	-160
F_1	308	308	0	295	295	0
(2)	i + t̤			(5)	t̤ + i	
F_4	3650	3675	+25	3755	3750	+5
F_3	2925	2875	-50	2745	3100	-355
F_2	2425	2388	-38	2290	2445	-155
F_1	313	313	0	300	300	0
(2)	i + d̤			(4)	d̤ + i	
F_4	3650	3600	-50	3688	3688	0
F_3	2650	2600	-50	2638	3200	-563
F_2	2300	2175	-125	2206	2444	-238
F_1	313	313	0	300	300	0

Table D.9

Formant transitions of the vowel e adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1)	e + t			(3)	t + e	
F_4	3900	3900	0	3767	3683	+83
F_3	2800	2700	-100	2567	2600	-33
F_2	2175	1900	-275	2000	2100	-100
F_1	550	450	-100	417	417	0
(1)	e + d			(3)	d + e	
F_4	3900	4000	+100	3750	3725	+25
F_3	2700	2600	-100	2592	2633	-42
F_2	2075	1900	-175	1935	2092	-157
F_1	475	400	-75	408	425	-17
(1)	e + ṭ			(4)	ṭ + e	
F_4	3850	3850	0	3744	3719	25
F_3	2750	2700	-50	2531	2538	-6
F_2	2200	2125	-75	2050	2100	-50
F_1	475	400	-75	475	475	0
(1)	e + ḍ			(3)	ḍ + e	
F_4	3800	3800	0	3650	3650	0
F_3	2600	2750	+150	2533	2550	-17
F_2	2200	2150	-50	1867	2033	-166
F_1	450	350	-100	458	458	0

Table D.10

Formant transitions of the vowel a adjacent to labial, velar, and palatal stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	a + p			(7)	p + a	
F_4	3575	3675	+100	3643	3579	+64
F_3	2400	2350	-50	2450	2443	+7
F_2	1288	1263	-25	1175	1236	-61
F_1	838	725	-113	743	857	-114
(2)	a + b			(4)	b + a	
F_4	3500	3450	-50	3519	3538	-19
F_3	2388	2350	-38	2506	2563	-57
F_2	1275	1200	-75	1138	1213	-75
F_1	825	675	-150	631	831	-200
(2)	a + k			(3)	k + a	
F_4	3625	4175	+550	3692	3475	+217
F_3	2375	2113	-262	2183	2400	-217
F_2	1250	1325	+75	1425	1316	+109
F_1	850	650	-200	700	825	-125
(2)	a + g			(3)	g + a	
F_4	3400	3800	+400	3633	3617	+16
F_3	2500	2100	-400	2325	2383	-58
F_2	1200	1300	+100	1508	1308	+200
F_1	825	700	-125	517	775	-258

Table D.10 (continued)

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1)	c + a			(1) j + a		
F_4	3750	3500	+150	3700	3400	+300
F_3	2500	2300	-200	2800	2400	+400
F_2	1800	1400	+400	2100	1375	+725
F_1	500	800	-300	400	775	-375

Table D.11

Formant transisions of the vowel ə adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans start	Steady state	diff.
(1)	p + ə			(1)	b +ə	
F_4	3250	3300	-50	3300	3300	0
F_3	2475	2475	0	2500	2600	-100
F_2	1000	1050	-50	925	1175	-250
F_1	575	600	-25	550	650	-100
(1)	k + ə					
F_4	3450	3325	+125			
F_3	2300	2375	-75			
F_2	1175	1175	0			
F_1	500	625	-125			
(1)	c + ə			(1)	j + ə	
F_4	3525	3425	+100	3550	3350	+200
F_3	2475	2275	+200	2775	2225	+550
F_2	1900	1250	+650	2000	1250	+750
F_1	400	600	-200	400	625	-225

Table D.11 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	$\underline{\partial} + \underline{g}$			(3)	$\underline{g} + \underline{\partial}$	
F_4	3425	3550	+125	3533	3400	+133
F_3	2200	2213	+13	2308	2300	+8
F_2	1413	1450	+37	1425	1333	+92
F_1	550	500	-50	475	567	-92

Table D.12

Formant transitions of the vowel u adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1)	p + u			(1)	b + u	
F_4	3400	3400	0	3250	3250	0
F_3	2400	2400	0	2500	2500	0
F_2	725	725	0	725	725	0
F_1	400	400	0	375	375	0
(4)	k + u			(2)	g + u	
F_4	3483	3433	+50	3650	3650	0
F_3	2350	2400	-50	2250	2500	-250
F_2	731	731	0	737	737	0
F_1	381	381	0	350	350	0
(1)	c + u			(1)	j + u	
F_4	3200	3400	-200	3200	3400	-200
F_3	2275	2425	-150	2250	2350	-100
F_2	1725	900	+825	2000	850	+1150
F_1	400	400	0	375	375	0

Table D.13

Formant transitions of the vowel o adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1)	p + o			(1)	b + o	
F_4	3200	3200	0	3150	3150	0
F_3	2725	2700	+25	2650	2750	-100
F_2	700	700	0	800	850	-50
F_1	400	400	0	350	425	-75
(1)	k + o			(1)	g + o	
F_4	3350	3100	+250	3250	3150	+100
F_3	2300	2500	-200	2300	2550	-250
F_2	850	850	0	875	875	0
F_1	475	500	-25	450	500	-50
(1)	c + o			(1)	j + o	
F_4	3300	3250	+50	3300	3200	+100
F_3	2200	2350	-150	2200	2400	-200
F_2	1625	950	+675	2000	875	+1125
F_1	425	500	-75	400	450	-50

Table D.14

Formant transitions of the vowel i adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(3)	p + i			(2)	b + i	
F_4	3675	3675	0	3563	3725	-162
F_3	2875	3000	-125	2750	3350	-600
F_2	2283	2350	-67	2268	2350	-82
F_1	292	300	-8	313	313	0
				(3)	g + i	
F_4				3650	3633	-17
F_3				3167	3100	+67
F_2				2483	2350	-113
F_1				283	308	25
(1)	c + i			(1)	j + i	
F_4	3750	3750	0	3700	3700	0
F_3	3250	3250	0	3200	3200	0
F_2	2350	2400	-50	2200	2325	-125
F_1	300	300	0	275	300	-25

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1)	i + k			(4)	k + i	
F_4	3725	3725	0	3731	3731	0
F_3	2900	2550	-350	3100	3138	-38
F_2	2400	2500	-100	2433	2450	-17
F_1	300	300	0	306	306	0

Table D.15

Formant transitions of the vowel e adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1)	p + e			(1)	b + e	
F_4	3575	3675	-100	3400	3700	-300
F_3	2475	2600	-125	2400	2600	-200
F_2	2050	2200	-150	1875	2175	-300
F_1	400	450	-50	400	400	0
(1)	k + e			(1)	g + e	
F_4	3700	3650	+50	3750	3600	+150
F_3	2600	2700	-100	2450	2600	-150
F_2	2250	2200	+50	2350	2250	+100
F_1	400	425	-25	375	400	-25
(1)	c + e			(1)	j + e	
F_4	3650	3650	0	3775	3600	+175
F_3	2750	2600	+150	2950	2675	+275
F_2	2200	2100	+100	2225	2200	+25
F_1	400	425	-25	275	375	-100

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STUDIES IN GUJARATI PHONOLOGY AND PHONETICS

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Following a general introduction (Chapter I), Chapter II presents a phonological description of Gujarati. Thirty phonemes are posited and described according to the Theory of Distinctive Features of Roman Jakobson. Nine feature oppositions are employed. The problems arising are critically examined with possible solutions. The feature systems of Generative Phonology and of Peter Ladefoged are briefly discussed.

Chapter III presents an acoustic analysis of Gujarati vowels. The main characteristics of the nasalized vowels as compared to the clear vowels are: (1) No change in the fundamental frequency; (2) The first formant of the open vowels is generally higher and weakened; (3) A sub-formant appears in the open vowels; (4) A zero seems to be at around 400-500 Hz; (5) Small peaks are seen at irregular intervals. The murmured or breathy vowels are characterized by (1) A strong air-flow; (2) Longer duration, a low frequency start, and a dip in the frequency in the beginning; (3) A slower rise in the intensity at the start; (4) No difference in the formant frequencies.

Next follows the phonetic analysis of the retroflex and dental consonants in Chapter IV. Direct palatography is used. The place of articulation for the dental stops is dental or dentialveolar (r is mostly

alveolar), whereas the retroflex stops are prepalatal, but postalveolar in combination with i. ḷ,ṇ.ṛ, are palatal retroflex flaps. The acoustic analysis of the retroflex and dental consonants is done on the basis of spectrograms. The burst analysis is done by a computerized linear prediction analysis method. The main results of the acoustic investigation are: (1) Retroflex ḷ and ṇ have a lower F_3 and F_4 than dental l and n, and ḷ has a higher F_1 than l; (2) All retroflex consonants have a lowering effect on F_3 and F_4 of the surrounding vowels, particularly of the preceding vowels, as compared to the dental consontants. The effect of retroflex consonants on the following vowel is much more irregular. (3) The F_3 and F_4 transitions of the vowel preceding the retroflex consonants are generally negative. (4) An important characteristic of retroflex consonants is said by earlier researchers to be a clustering of F_2, F_3 and F_4 in a relatively narrow frequency region. The present investigation confirms this; (5) The closure duration for d - ḍ is shorter than for t - ṭ. There is also a tendency for the retroflex consonants to have a slightly shorter closure than the dental consonants, but this difference is not consistent; (6) The VOT (voice onset time) value is smaller for retroflex consonants than for dental consonants; (7) The burst has more energy at lower frequencies before retroflex stops than before dental stops. (8) Although the dental and retroflex stops are less clearly distinguished in the position following a vowel, it seems that there is no possibility of confusing them with other stops. The similarity in formant transitions between velars and retroflex stops is found only after the vowel a, and to a certain extent also before the vowel a. This confirms the findings of other researchers; (9) The F_2 locus is 1700 for dentals, and 2100 for retroflex

stops. The F_3 locus for dentals is approximately at 2700 Hz. The F_4 locus is only a guess at 3500 Hz. F_3 and F_4 of retroflex stops do not point to a definite frequency. They go downward. The lowest points are 1800 and 2750 for the F_3 and F_4 transitions respectively.

These results are summarized, and critically compared with the results of other investigators. An effort is made to explain the relation between the acoustic results and articulation. Jakobson's description of the retroflex consonants needs verification.

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AUTOBIOGRAPHICAL SKETCH

I was born in Pad-dhari, Gujarat state, India, in the year 1928.

I received my Bachlor of Arts (Honours) degree from the University of Bombay in 1949 with Sanskrit Honours and Gujarati subsidiary. I completed my Maters of Arts degree from Gujarat University in 1952 with Sanskrit Principal and Gujarati subsidiary. My specialization was in the Vedanta philosophy. I earned another Master of Arts degree from Banaras Hindu University in 1955 with Hindi. Pali and Prakrit were obligatory languages in Banaras. I also hold Rashtrabhasha Kovid and Rashtrabhasha Ratna degrees in Hindi from the Rashtrabhasha Prachar Samiti, Wardha.

My first studies in linguistics were carried out from 1952-53 when I was working for my Rashtrabhasha Ratna degree. I studied linguistics again in 1954-55 while working for my M.A. degree in Banaras. In 1964, I went to the Deccan College, Poona, to study linquistics. I attended the summer schools of linguistics in 1964 and 1965 at Trivendrum and Pachmarhi respectively. I also studied German in 1964 and passed the Grundstufe I and II examinations in Poona.

In August 1965 I went to Copenhagen, Denmark, on a fellowship first from the Danish Ministry of Education and later from the Ministry of Foreign Affaris. I studied general linguistics and general phonetics at the Institute of Linguistics and Phonetics, University of Copenhagen. I concentrated on Acoustic and Experimental phonetics, and also did some acoustic research.

I came to Cornell University in Fall, 1968, under the Humanities and Social Sciences Fellowship Program of Cornell. I received my Master's degree in linguistics in 1971. My acoustic research on Gujarati vowels was completed when I left Copenhagen in 1968. The research on Gujarati consonants was, however, incomplete. In April 1977, I went to Copenhagen for six weeks and completed it.

I worked as a teacher in several high schools of Bhavnagar, India from 1949 to 1955. I worked as a lecturer in Hindi in Smt. M.C. Gandhi Mahila College, Bhavnagar, from 1955 to 1962. I also taught Hindi for one semester in the Institute of Indian Philology of Copenhagen University in 1965. Under the fellowship program of Cornell, I worked as a teaching fellow in linguistics for one and a half years.

I have also worked for the propagation of Hindi as a national language from 1950 to 1964. I also taught Hindi in the evening class of the Bhavnagar Rashtrabhasha Prachar Samiti, a branch of the Rashtrabhasha Pracher Samit, Wardha. This was a voluntary service.

I served for three years as a member of the Board of Studies in Hindi of the S.N.D.T. Women's University, Bombay. I also served the same university as a senator for two years.

I worked for the Ithaca Journal, Ithaca, New York, from 1972-73. Since 1973, I have been working in the Olin Library of Cornell University.

I married in 1969, have become permanent resident of the United States, and live in Ithaca with my wife and son.

For

Eli Fischer-Jørgensen